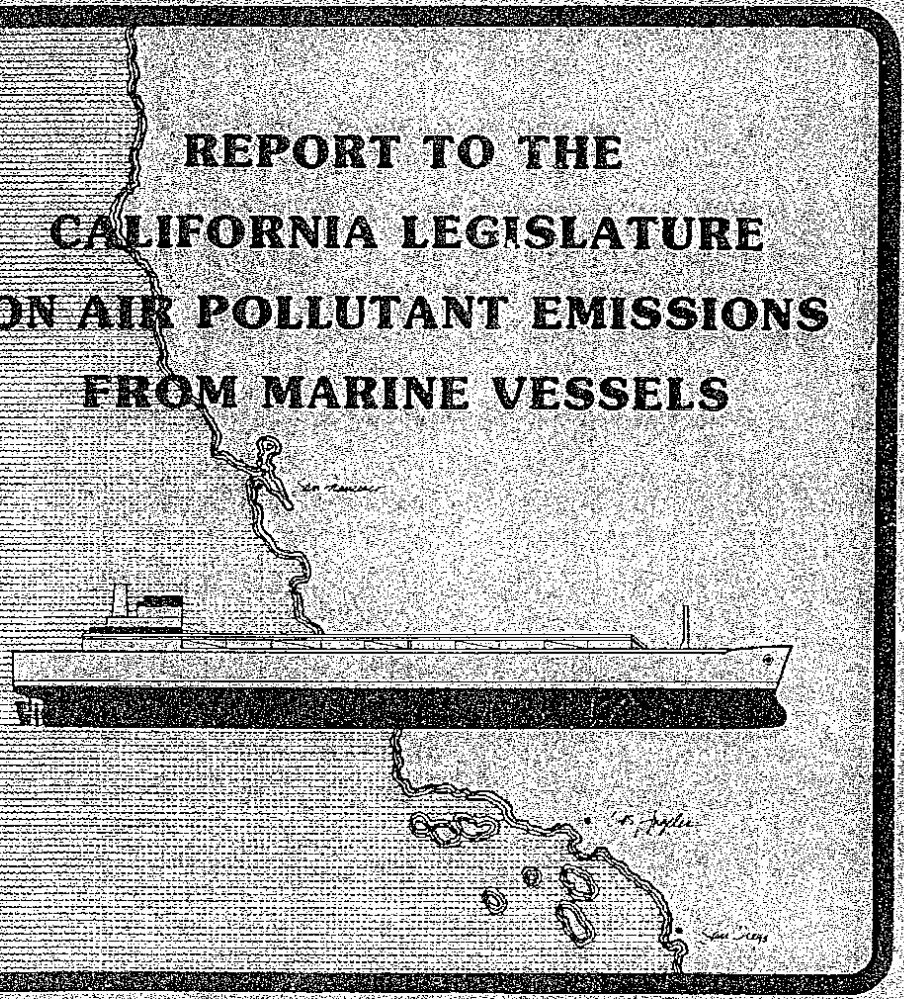
State of California

AIR RESOURCES BOARD

REPORT TO THE CALIFORNIA LEGISLATURE ON AIR POLLUTANT EMISSIONS FROM MARINE VESSELS



Volume I

June 1984

C. COASTAL CALIFORNIA METEOROLOGY

California Coastal Waters have been defined as that area between the California coastline and a line starting at the California - Oregon border at the Pacific Ocean

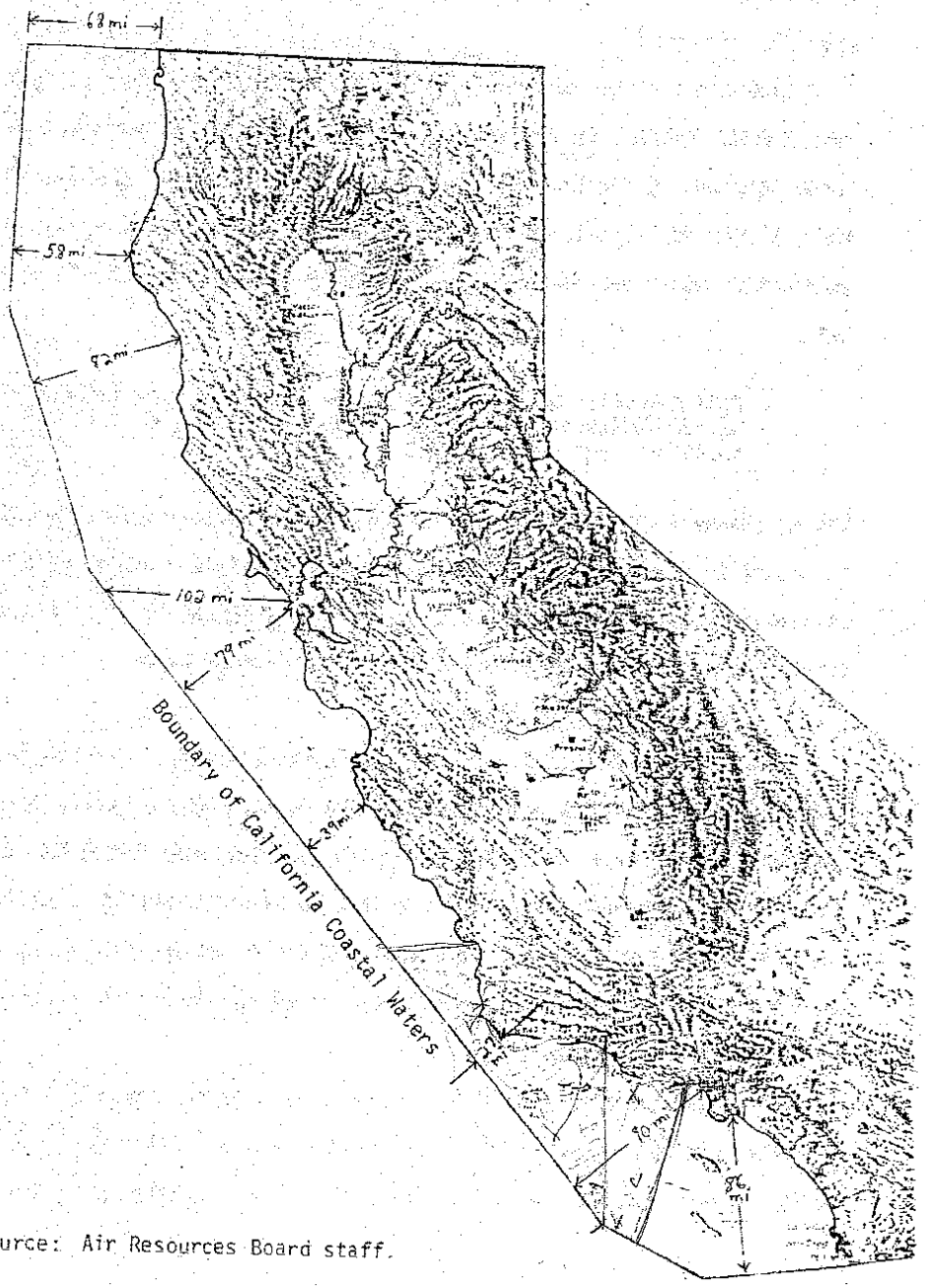
thence to 42.0° 125.5°W
thence to 41.0°N 125.5°W
thence to 40.0°N 125.5°W
thence to 39.0°N 125.0°W
thence to 38.0°N 124.5°W
thence to 37.0°N 123.5°W
thence to 36.0°N 122.5°W
thence to 35.0°N 121.5°W
thence to 34.0°N 120.5°W
thence to 33.0°N 119.5°W
thence to 32.5°N 118.5°W

and ending at the California-Mexico border at the Pacific Ocean. The California Coastal Waters are shown on Figure VI-6.

The line describing California Coastal Waters does not form a political boundary but it is useful in describing the fate of pollutants emitted off the California coast. The definition of California Coastal Waters was developed by the ARB meteorology staff and was originally presented as Appendix A to the ARB staff report, Status Report Regarding Adoption by Local Air Pollution Control Districts of Rules for the Control of Emissions from Lightering Operations, February 23, 1978. California Coastal Waters as defined above is the area offshore of California within which pollutants are likely to be transported ashore and affect air quality in California's coastal air basins, particularly during the summer. Pollutant emissions released somewhat to the west of these waters in summer are likely to be transported southward, parallel to the coast. Most coastal marine traffic passes 3 to 15 miles from

FIGURE VI-6

CALIFORNIA COASTAL WATERS



Source: Air Resources Board staff.

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* This report is comprised of seven volumes. Volume One contains the Summary and Chapters I through VII; Volume Two contains Chapters VIII through XI; Volume Three contains Appendices A-1 through A-4; Volume Four contains Appendices A-5 through A-7; Volume Five contains Appendices A-8 through A-10, B and C; Volume Six contains Appendices D through G; and Volume Seven contains Appendices H through M.

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* The appendices are printed in five volumes. Volume Three contains Appendices A-1 through A-4; Volume Four contains Appendices A-5 through A-7; Volume Five contains Appendices A-8 through A-10, B, and C; Volume Six contains Appendices D through G; and Volume Seven contains Appendices H through M.

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VI. NEED FOR EMISSIONS REDUCTIONS

A. PREFACE

Three meetings of the Marine Vessel Emissions Task Force were held to discuss the need to reduce emissions from marine vessels. The following sections of this chapter detail industry views and staff findings. State and federal ambient air quality standards are outlined along with the need and bases of the standards. The extent of violations of the standards occurring in California coastal air basins is presented. Coastal California meteorology, including the Pacific high pressure cell, wind flow patterns, land/sea breezes, atmospheric inversions, and fog, is discussed in relation to the transport of pollutants. Evidence from studies in which inert gases were released from vessels offshore and the paths of the inert gases were traced to shore (tracer studies) is presented. Results of mathematical modeling of emissions from marine vessels are given. Finally, the impact of emissions from marine vessels on ambient air quality is assessed.

B. EXISTING AMBIENT AIR QUALITY

1. Ambient Air Quality Standards and Air Quality Monitoring

Recognizing that certain minimum standards are required to protect the public health and welfare, national and state ambient air quality standards have been established. The Clean Air Act of 1970 authorizes the U. S. Environmental Protection Agency (EPA) to set standards and to oversee the development and implementation of state plans that would lead to attainment and maintenance of the nationwide standards.[1/] In addition, the Air Resources Board has established ambient air quality standards, as authorized by the California Health and Safety Code.[2/] Standards have been set for all major pollutants, including oxidant or ozone, nitrogen dioxide, sulfur

dioxide, suspended particulate matter, and sulfates.

The federal and state standards have been established in consideration of public health, aesthetics, visibility, and effects on the economy.[2/] The EPA set primary standards to reflect consideration of public health and secondary standards to reflect consideration of public welfare. The Air Resources Board established one set of standards for each pollutant, based on both public health and welfare. Table VI-I lists the national and California standards. As the table shows, the state has set a standard for oxidant, whereas the national standard is for ozone; however, the state now measures ozone only and the state standard is, in effect, an ozone standard. Ozone is a pollutant which is produced by chemical reactions of nitrogen oxides and hydrocarbons in the presence of sunlight. The table also shows that the state sulfur dioxide standard is different from the federal standard. The state standard is the occurrence of a 24-hour sulfur dioxide concentration of 0.05 ppm or higher in combination with either (1) an hourly ozone level equalling or exceeding 0.10 ppm or (2) a 24-hour concentration of total suspended particulate (TSP) equalling or exceeding 100 ug/m^3. Violation of the 24-hour federal sulfur dioxide standard of 0.14 ppm does not require the presence of high concentrations of ozone or TSP. Table VI-1 also shows that the state annual geometric mean and 24-hour TSP standards are more stringent than their federal counterparts. Also, the state standard for nitrogen dioxide is set for a different averaging time than the federal standard. The table also shows that the state has a standard for sulfates, whereas there is currently no national standard for this pollutant.

The Air Resources Board and air pollution control and air quality management districts have established ambient air quality monitoring stations

TABLE VI-1

AMBIENT AIR QUALITY STANDARDS

Pollutant	Averaging Time	California Standards[1]		National Standards[2]		
		Concentration[3]	Method[4]	Primary[5,6]	Secondary[5,6]	Method[7]
Oxidant[10]	1 hour	0.10 ppm (200 ug/m³)	Ultraviolet Photometry	—	—	—
Ozone	1 hour	—	—	0.12 ppm (235 ug/m³)	Same as Primary Standard	Ethylene Chemiluminescence
Carbon Monoxide	8 hour	9.0 ppm (10 mg/m³)	Non-Dispersive Infrared Spectroscopy (NDIR)	10 mg/m³ (9 ppm)	Same as Primary Standards	Non-Dispersive Infrared Spectroscopy (NDIR)
	1 hour	20 ppm (23 mg/m³)		40 mg/m³ (35 ppm)		
Nitrogen Dioxide	Annual Average	—	Gas Phase Chemiluminescence	100 ug/m³ (0.05 ppm)	Same as Primary Standard	Gas Phase Chemiluminescence
	1 hour	0.25 ppm (470 ug/m³)		—		
Sulfur Dioxide	Annual Average	—	Ultraviolet Fluorescence	80 ug/m³ (0.03 ppm)	—	Pararosaniline
	24 hour	0.05 ppm (131 ug/m³)[8]		365 ug/m³ (0.14 ppm)	—	
	3 hour	—		—	1300 ug/m³ (0.5 ppm)	
	1 hour	0.5 ppm[9] (1310 ug/m³)		—	—	
Suspended Particulate Matter	Annual Geometric Mean	60 ug/m³ [11]	High Volume Sampling	75 ug/m³	60 ug/m³	High Volume Sampling
	24 hour	100 ug/m³ [11]		260 ug/m³	150 ug/m³	
Sulfates	24 hour	25 ug/m³	Turbidimetric Barium Sulfate	—	—	—
Lead	30 day Average	1.5 ug/m³	Atomic Absorption	—	—	—
	Calendar Quarter	—	—	1.5 ug/m³	Same as Primary Standard	Atomic Absorption
Hydrogen Sulfide	1 hour	0.03 ppm (42 ug/m³)	Cadmium Hydroxide STRactan	—	—	—
Vinyl Chloride (Chloroethene)	24 hour	0.010 ppm (26 ug/m³)	Tedlar Bag Collection, Gas Chromatography	—	—	—
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility[8] to less than 10 miles when the relative humidity is less than 70%		—	—	—
APPLICABLE ONLY IN THE LAKE TAHOE AIR BASIN:						
Carbon Monoxide	8 hour	6 ppm (7 mg/m³)	NDIR	—	—	—
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility[8] to less than 30 miles when the relative humidity is less than 70%		—	—	—

(Footnotes on following page.)

Source: Air Resources Board staff.

TABLE VI-1

AMBIENT AIR QUALITY STANDARDS
(Continued)

NOTES:

a/ California standards, other than carbon monoxide, are values that are not to be equaled or exceeded. The carbon monoxide standards are not to be exceeded.

b/ National standards, other than ozone and those based on annual averages or annual geometric means, are not to be exceeded more than once a year. The ozone standard is attained when the expected number of days a calendar year with a maximum hourly average concentration above the standard is equal to or less than one.

c/ Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury. All measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 mm of Hg (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.

d/ Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.

e/ National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).

f/ National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after the implementation plan is approved by the EPA.

g/ Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" and must be approved by the EPA.

h/ Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

i/ At locations where the state standards for oxidant and/or suspended particulate matter are violated. National standards apply elsewhere.

j/ Measured as ozone.

k/ On November 18, 1983, the Board approved a new 1-hour standard for ambient concentrations of sulfur dioxide of 0.25 ppm or about 655 ug/m^3. That standard will be in effect following its approval by the Office of Administrative Law.

l/ New California suspended particulate matter standards became effective in December 1983. The standards are for suspended particulate matter smaller than 10 microns in diameter. The standards for particles in that size are 30 ug/m^3 annual geometric mean and 50 ug/m^3 for a 24-hour period.

in the coastal air basins. The data from these stations are used to determine whether ambient air quality standards have been violated in specific areas. Figure VI-1 shows all of the coastal monitoring stations that were operating during 1981. The figure shows that monitoring stations are widely distributed on the coast and that numerous stations are operated in the major metropolitan areas of the South Coast and San Francisco Bay Area Air Basins.

2. Health Effects of Pollutants

The emissions that are of chief concern in this report are sulfur dioxide and hydrocarbons. The health effects of sulfur dioxide and the secondary pollutants produced from sulfur dioxide and hydrocarbons are discussed below.

a. Sulfur Dioxide

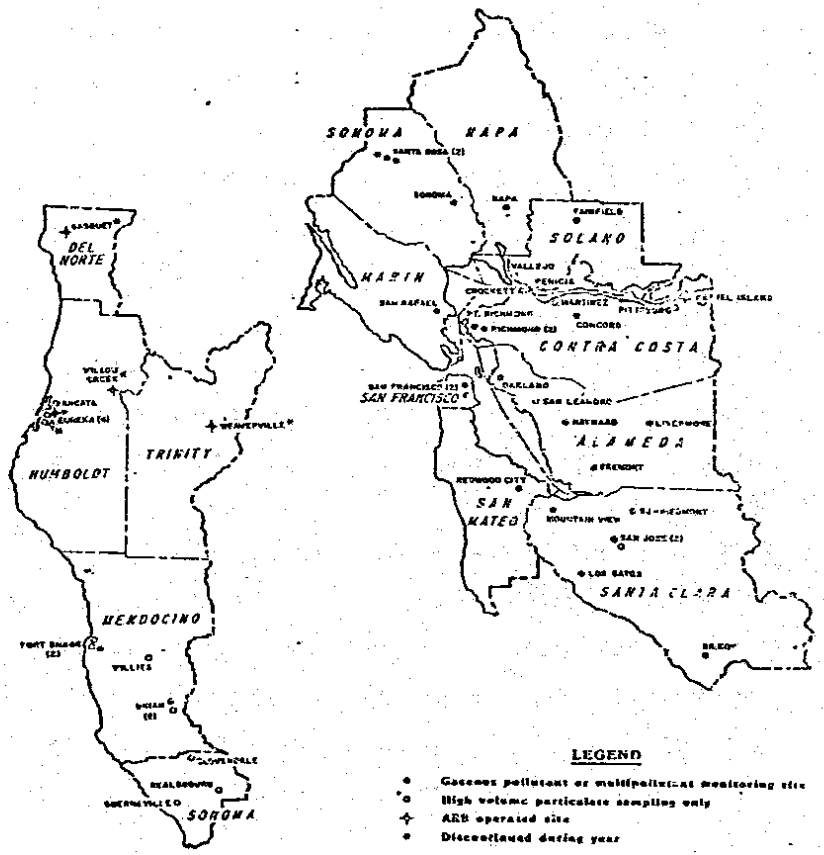
Sulfur dioxide alone is a mild respiratory irritant. Reactions to exposure to sulfur dioxide have been shown to be more severe in persons with asthma, especially in conjunction with exercise. The principal effect measured is bronchoconstriction or a tightening of the airways in the lungs which results in increased airway resistance.[3,4,5,6/]

Epidemiological studies have shown sulfur dioxide to be associated with the development and exacerbation of chronic respiratory conditions, especially when combined with particulate matter. Children have been shown to have a significantly higher prevalence and history of respiratory infections when exposed to sulfur dioxide and particulate matter pollution.[7,8/]

b. Sulfates

Sulfur dioxide can be oxidized in the atmosphere to form sulfate particles. Sulfates are normally found in the "fine" fraction of suspended particulate matter (diameter less than 2.5 micrometers) and therefore are in the size range that can be inhaled into the respiratory system.[9/] There is

SAN FRANCISCO BAY AREA AIR BASIN
MONITORING STATIONS OPERATING DURING 1981



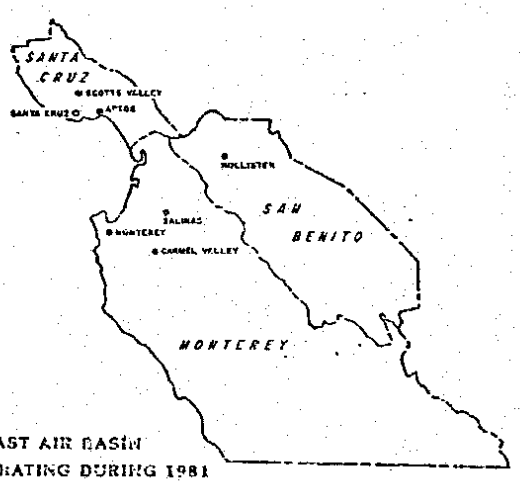
NORTH COAST AIR BASIN
MONITORING STATIONS OPERATING DURING 1981

FIGURE VI-1

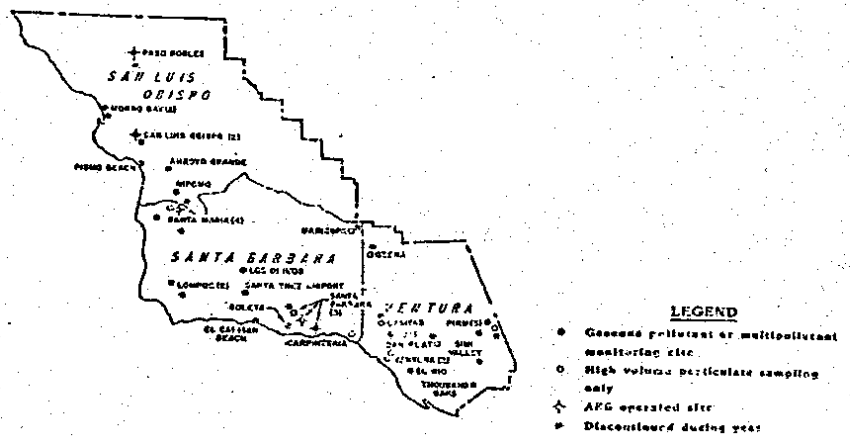
AIR QUALITY MONITORING STATIONS
IN CALIFORNIA'S COASTAL AIR BASINS

Source: Air Resources Board staff.

NORTH CENTRAL COAST AIR BASIN
MONITORING STATIONS OPERATING DURING 1981



SOUTH CENTRAL COAST AIR BASIN
MONITORING STATIONS OPERATING DURING 1981



LEGEND

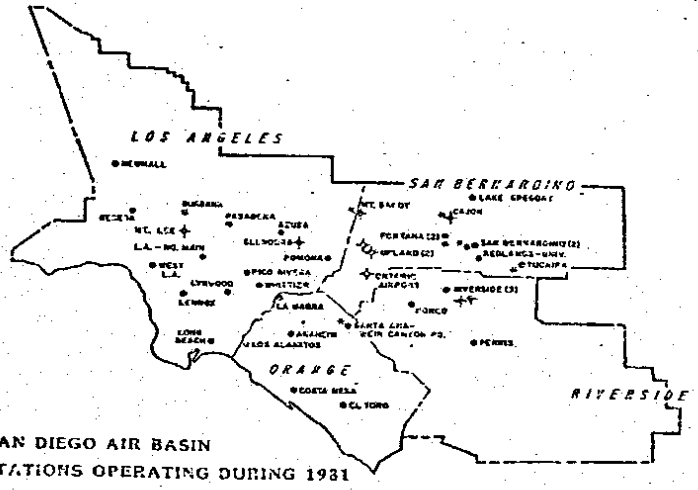
- Gaseous pollutant or multipollutant monitoring site
- High volume particulate sampling only
- APG operated site
- Discontinued during year

FIGURE VI-1
(Continued)

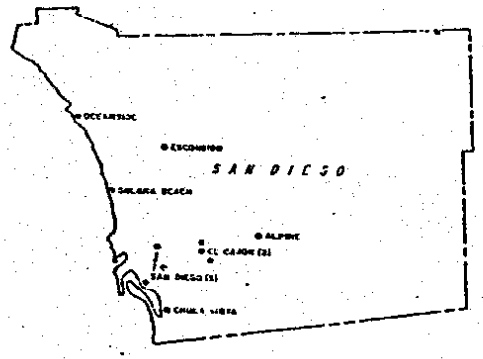
AIR QUALITY MONITORING STATIONS
IN CALIFORNIA'S COASTAL AIR BASINS

Source: Air Resources Board staff.

SOUTH COAST AIR BASIN
MONITORING STATIONS OPERATING DURING 1981



SAN DIEGO AIR BASIN
MONITORING STATIONS OPERATING DURING 1981



LEGEND

- Gaseous pollutant or multipollutant monitoring site
- High volume particulate sampling only
- ARB operated site
- Discontinued during year

FIGURE VI-1
(Continued)

AIR QUALITY MONITORING STATIONS
IN CALIFORNIA'S COASTAL AIR BASINS

Source: Air Resources Board staff.

limited dose-response information available for effects attributable directly to sulfates but they are believed to aggravate asthma, lung, and heart disease, and lung function in children. In addition to the particle size, effects may be influenced by other variables such as weather conditions (e.g., high humidity enhances sulfate formation) and the presence of other pollutants.[10/]

c. Suspended Particulate Matter

Sulfur dioxide and hydrocarbons are, at least in part, converted in the atmosphere to suspended particulate matter. Particles small enough to be inhaled into the respiratory system (diameter less than 10-15 micrometers) are of most concern for health protection. Suspended particulate matter may cause adverse effects by a number of mechanisms. These mechanisms include chemical or mechanical irritation, alteration of host defense mechanisms (e.g., clearance mechanisms), direct or indirect damage (e.g., acid aerosols, silica) or systemic toxicity (e.g., lead). The resulting effects associated with exposure to particulate matter include effects on respiratory mechanics, aggravation of existing respiratory and cardiovascular disease, effects on clearance and other host defense mechanisms, morphological alterations, carcinogenesis, and mortality.[9,11/]

d. Ozone

Ozone is formed in the atmosphere by chemical reactions of two other pollutants, hydrocarbons and nitrogen oxides. These reactions require energy which is provided by sunlight. Ozone, the largest component of the smog complex, is a strong respiratory irritant. It irritates the mucous membrances of the respiratory system and impairs normal function of the lung. This impairment is accompanied by such symptoms as chest tightness, coughing, and

wheezing. Ozone has been shown to aggravate chronic respiratory diseases such as asthma and bronchitis. Peroxyacetal nitrates (PAN) and the other oxidants formed in the atmosphere along with ozone are strong eye irritants.[12/]

3. Coastal California Air Quality

All of the coastal air basins in California experience violations of ambient air quality standards. Table VI-2 is a compendium of the ambient air quality in California coastal air basins for ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, sulfate, and total suspended particulate (TSP) during the period 1979 through 1981. The data presented in Table VI-2 are discussed below.

a. Violations of State and Federal Standards

The one hour national ambient air quality standard for ozone of 0.12 ppm was exceeded in all of California's coastal air basins from the San Francisco Bay Area southward in the years 1979 through 1981. The frequency of the violations in 1981 ranged from 2 days in the North Central Coast Air Basin to 187 days in the South Coast Air Basin. The California standard for oxidant (measured as ozone) of 0.10 ppm was exceeded in all coastal air basins during the period 1979 through 1981. The frequency of the violations in 1981 ranged from 8 days in the North Central Coast Air Basin, to 233 days in the South Coast Air Basin.

Violations of the California standard for nitrogen dioxide, 0.25 ppm for 1 hour, occurred in the San Francisco Bay Area, South Coast, and San Diego Air Basins in the period 1979-1981. The most frequent violations occurred in the South Coast Air Basin. The nitrogen dioxide standard was violated on 44 and 38 days in the South Coast Air Basin in 1980 and 1981, respectively. The annual average national ambient air quality standard for nitrogen dioxide of

TABLE VI-2

SUMMARY OF AIR QUALITY IN COASTAL AIR BASINS

1979-1981

POLLUTANT	CONCENTRATION	North Coast			San Francisco Bay Area			North Central Coast			South Central Coast			South Coast			San Diego		
		1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981
OZONE	One Hour Avg ≥.10 ppm (days)	1	0	0	60	46	51	5	15	8	146	143	151	228	210	233	138	107	102
	One Hour Avg ≥.12 ppm (days)	0	0	0	15	18	8	0	2	2	73	61	85	193	167	187	66	87	70
	High (ppm)	.10	.08	.09	.19	.20	.18	.10	.14	.14	.23	.21	.24	.47	.49	.39	.26	.23	.29
	Second High (ppm)	.09	.08	.09	.17	.19	.18	.10	.14	.14	.22	.20	.23	.46	.44	.37	.26	.23	.26
	One Hour Avg ≥.20 ppm (days)	0	0	0	0	1	0	0	0	0	2	1	3	123	102	105	10	8	2
CARBON MONOXIDE	Eight Hour Avg >9.3 ppm (days)	0	0	--	20	15	6	0	0	0	7	6	0	94	94	80	10	1	1
	12 Hour Avg ≥10 ppm (days)	0	0	--	10	5	1	0	0	0	0	0	0	62	60	60	0	0	0
NITROGEN DIOXIDE	One Hour Avg ≥.25 ppm (days)	--	--	0	0	1	0	0	0	0	0	0	0	76[a]	44	38	0	0	1
	24 Hour Avg ≥.05 ppm (days)	--	--	0	0	0	0	1	0	0	0	0	0	13[b]	2[b]	0	0	0	0
SULFUR DIOXIDE	High (ppm)	--	--	.003	.027	.039	.033	.057	.003	.008	.035	.033	.038	.079	.068	.044	.040	.042	.028
	Second High (ppm)	--	--	.002	.025	.035	.026	.044	.002	.006	.033	.030	.036	.079	.051	.041	.040	.036	.027
	One Hour Avg ≥.5 ppm (days)	--	--	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High (ppm)	--	--	.02	.12	.14	.09	.24	.02	.02	.12	.17	.27	.18	.17	.16	.09	.13	.12
	Second High (ppm)	--	--	.01	.11	.14	.09	.12	.01	.02	.11	.17	.23	.17	.16	.14	.07	.11	.10
SULFATE	24 Hour Avg ≥25 $\mu g/m^3$ (days)	0	0	0	0	0	0	0	0	0	0	3	0	22	35	18	0	2	0
	Number of Sampling Days	61	53	53	71	69	65	62	59	60	140	147	146	361	366	359	63	65	63
	Percent ≥ 25 $\mu g/m^3$	0	0	0	0	0	0	0	0	0	0	2	0	6	10	5	0	3	0
	High ($\mu g/m^3$)	7.9	7.5	6.2	17.7	16.0	16.3	14.8	8.7	7.3	19.5	31.0	22.7	37.9	50.2	48.4	14.2	28.2	23.7
	Second High ($\mu g/m^3$)	7.4	7.5	6.6	15.7	15.2	15.6	14.0	8.5	6.1	19.2	29.3	21.8	36.1	50.2	42.4	14.1	27.9	19.5
	24 Hr Avg ≥25 $\mu g/m^3$ combined with ozone one hour avg ≥.20 ppm (days)	0	0	0	0	0	0	0	0	0	0	0	0	7	26	8	0	0	0
TOTAL SUSPENDED PARTICULATE	24 Hour Avg ≥100 $\mu g/m^3$ (days)	21	25	9	52	42	9	10	7	3	55	83	84	283	264	288	33	46	41
	Number of Sampling Days	60	60	01	162	123	69	63	61	62	152	161	207	366	366	362	64	79	66
	Percent ≥100 $\mu g/m^3$	32	37	11	32	34	13	25	11	5	36	52	41	78	72	80	51	58	48
	High ($\mu g/m^3$)	239	173	133	320	240	143	178	161	139	432	1366	518	417	511	602	180	225	271
	Second High ($\mu g/m^3$)	190	165	132	262	216	127	158	132	100	340	476	456	386	509	459	169	159	237
	Percent >250 $\mu g/m^3$	0	0	0	1	0	0	0	0	0	2	6	3	7	13	7	0	0	1

--Data not available.

[a] Measured nitrogen dioxide concentrations in 1979 were high due to a calibration bias. The standard exceedances in 1979 are not based on the adjusted concentrations. The number of standard violations is therefore less than 76 by an undetermined amount.

[b] California standard is 24 hours sulfur dioxide concentration ≥ 0.05 ppm in combination with a violation of either the state standard for ozone or total suspended particulate. Only one of the 1980 South Coast Air Basin measurements of sulfur dioxide ≥ 0.05 ppm was a probable violation; that is, the violation of the state TSP standard occurred at a nearby monitoring station. Twelve of the 13 measurements ≥ 0.05 ppm in 1979 were violations.

Source: Air Resources Board Technical Services Division.

0.05 ppm was also exceeded in the South Coast Air Basin in each of these three years.

The California 24-hour standard for sulfate of 25 ug/m^3 was violated in the South Central Coast, South Coast, and San Diego Air Basins in the period 1979-1981. Table VI-2 shows that in 1980 there were 3 measured sulfate violations in the South Central Coast Air Basin and 2 measured sulfate violations in the San Diego Air Basin. Because ambient sulfate measurements in those air basins were made on only 147 and 65 days, respectively, during 1980, it is reasonable to assume that, using proration, actual sulfate violations occurred on about 7 days in the South Central Coast Air Basin and 11 days in the San Diego Air Basin. There were 22 violations of the sulfate standard in the South Coast Air Basin in 1979, 35 in 1980, and 18 in 1981. The highest sulfate readings during this period occurred in 1980 and were twice the standard (50.2 ug/m^3). Sulfate standard violations were recorded at over 90 percent of the air monitoring stations at which sulfate was measured in the South Coast Air Basin during the period 1979 through 1981.

The 24-hour sulfate standard has not been violated in the past three years in the San Francisco Bay Area, North Central Coast, and North Coast Air Basins. Annual maximum 24-hour sulfate concentrations in 1979-1981 were 16.0 to 17.7 ug/m^3 in the San Francisco Bay Area Air Basin and 7.3 to 14.8 ug/m^3 in the North Central Coast Air Basin.

Since 1979, no sulfur dioxide standard violations have been recorded in California's coastal air basins. However, the California 24 hour sulfur dioxide standard, 0.05 ppm in combination with a high oxidant or TSP level, was violated on 12 days in the South Coast Air Basin during 1979, and one probable exceedance occurred in 1980. The highest 24-hour sulfur dioxide

concentration during 1979-1981 was 0.079 ppm and occurred in 1979 at Harbor City, near the coast. A major reason for the low ambient concentrations of sulfur dioxide is the greatly increased availability of natural gas to power plants. By burning clean natural gas instead of sulfur-bearing fuel oil, emissions of sulfur dioxide have been greatly reduced. However, if the availability of natural gas is reduced in the future, sulfur-bearing fuel oil will have to be burned again and ambient concentrations of sulfur dioxide would increase.

Table VI-2 shows that all of the coastal air basins experienced numerous, and in some cases extreme, violations of the 100 ug/m^3 state standard for TSP during 1979 through 1981. Twenty-four hour TSP concentrations of 518 ug/m^3, 602 ug/m^3 and 271 ug/m^3 were recorded in 1981 in the South Central Coast, South Coast, and San Diego Air Basins respectively. These concentrations of TSP also exceed the national primary standard of 260 ug/m^3. Most of the air monitoring stations in the South Coast Air Basin experienced violations of the state 24-hour and federal annual TSP standards and more than 48 percent of those air monitoring stations experienced violations of the federal 24-hour TSP standard in the period 1979-1981.[13,14,15/] Because TSP measurements are made with different frequencies in different air basins, the data on state TSP standard violation frequencies given in Table VI-2 are given in terms of percent of sampling days on which the TSP standard was violated. Since December 1983, the state standards for particulate matter have been based on particulates smaller than 10 microns in diameter. The annual 200 geometric mean and 24 hour standards are now 30 ug/m^3 and 50 ug/m^3 for suspended particulate matter smaller than 10 microns in diameter.

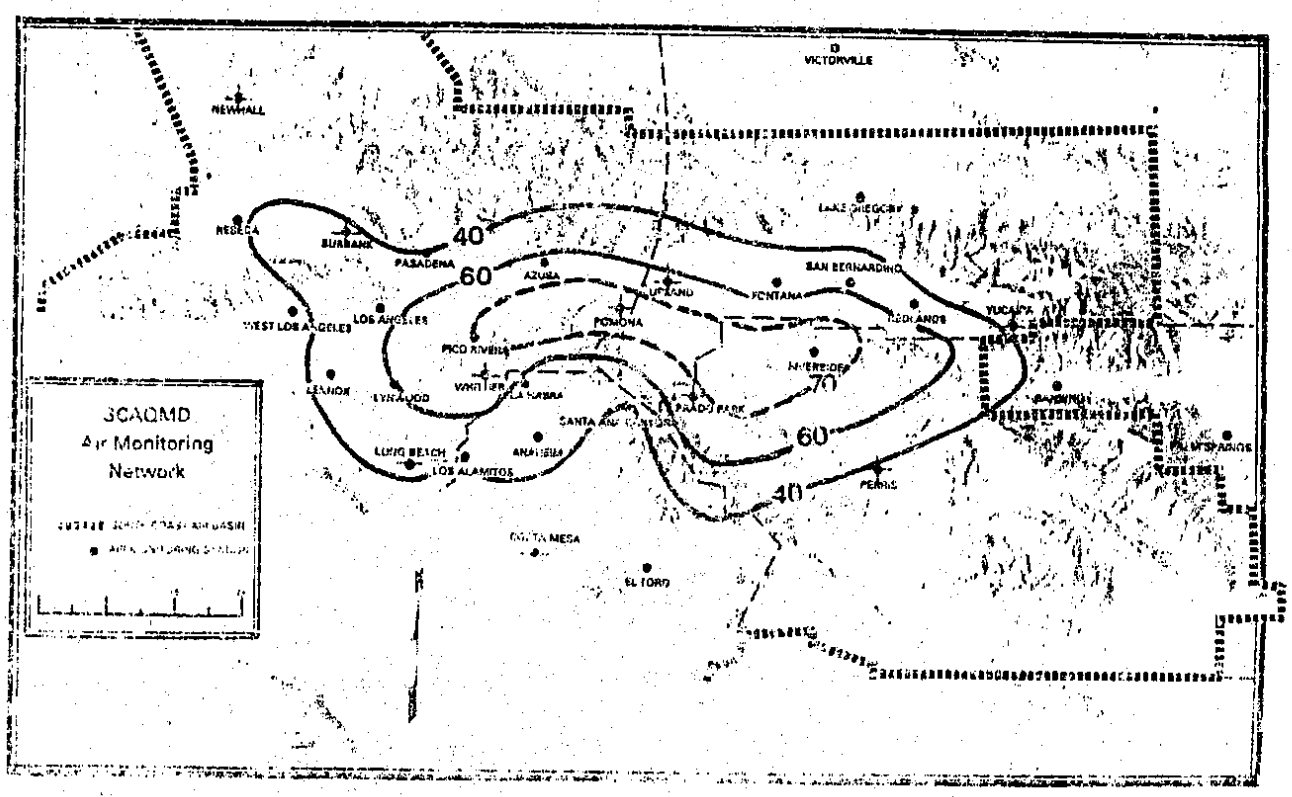
According to data in the annual ARB publications "California Air Quality Data"[13,14,15], sulfates contribute significantly to the annual geometric mean TSP mass. On an annualized basis, sulfate contributed from 6 to 15 percent of TSP in the South Coast Air Basin in 1979[16]. Two-hour "grab sample" air monitoring data reported for 1977[17] and 1973[18] show that sulfate accounted for 22 and 31 percent of the TSP measured at Anaheim and Dominguez Hills, respectively, in the South Coast Air Basin. Figures VI-2 and VI-3 show the frequency of violations in the South Coast Air Basin of the California sulfate standard and TSP standard respectively during 1980. Comparison of Figure VI-2 with VI-3 shows that sulfate and TSP violations occur with the greatest frequency in the same general areas.

The California visibility standard is exceeded when the prevailing visibility is reduced to less than 10 miles while the relative humidity is less than 70 percent. Figure VI-4 shows median 1 PM visibilities and visibility isopleths for California. The figure shows that coastal areas of California frequently experience visibilities in violation of the state standard. Table VI-3 shows the quarterly frequency of violation of the state visibility standard in coastal air basins in the period 1958-1977. The table shows that on a quarterly basis during that period the visibility standard was violated 10 to 42 percent of the time in the San Francisco Bay Area Air Basin, 6 to 52 percent of the time in the South Central Coast Air Basin, 15 to 63 percent of the time in the South Coast Air basin, and 21 to 37 percent of the time in the San Diego Air Basin. The visibility standard continues to be regularly violated throughout California's coastal areas.

Numerous studies have found that airborne particulate sulfates and nitrates contribute to visibility degradation in a ratio far exceeding the fraction of suspended aerosols represented by those species.[19,20,21,22]

FIGURE VI-2

TOTAL SUSPENDED PARTICULATE-1980
PERCENT OF DAYS ON WHICH STATE STANDARD WAS EXCEEDED
(24-HOUR AVERAGE TSP ≥ 100 $\mu g/m^3$)

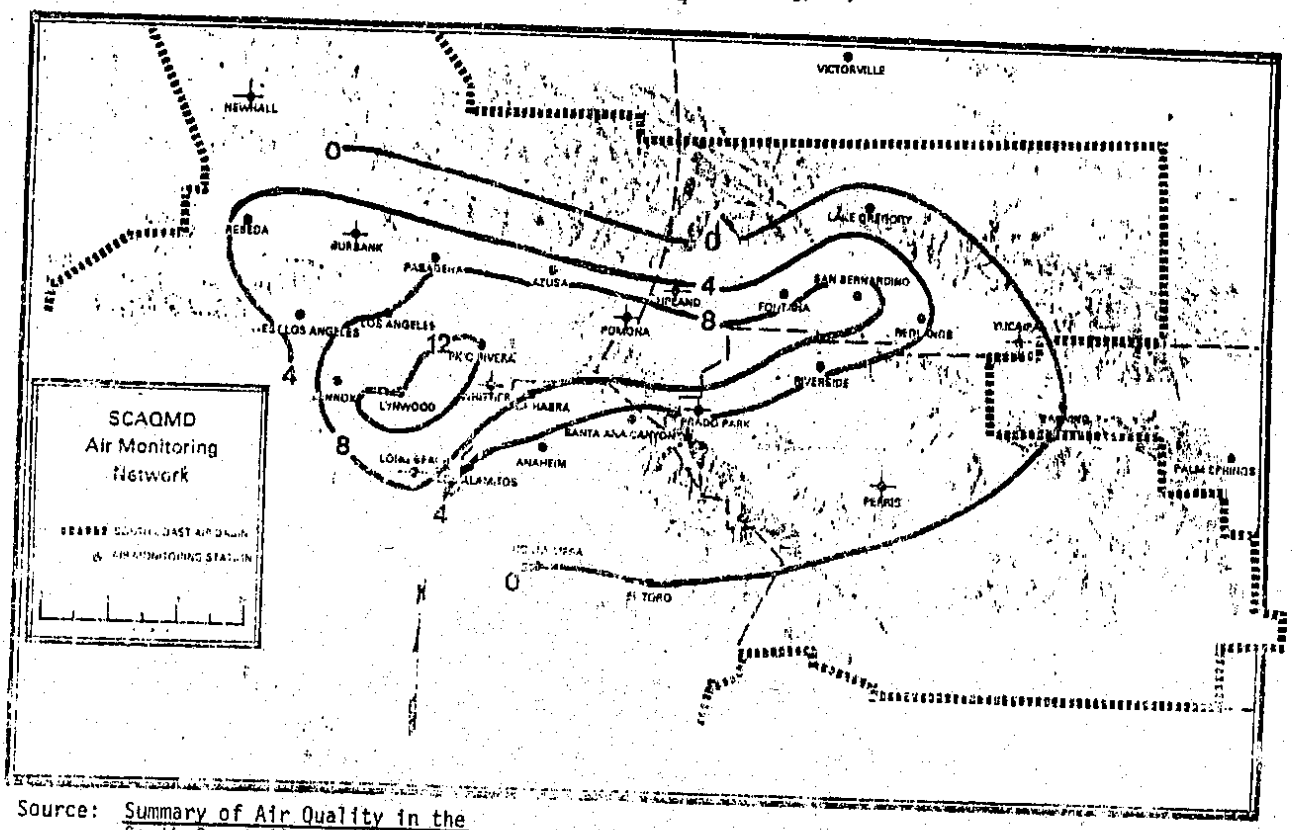


Source: Summary of Air Quality in the South Coast Air Basin of California, 1980, South Coast Air Quality Management District, May 1981.

—●— Less than 12 months of data.
—◆— Not measured at this location.
† Total suspended particulate is measured every sixth day.

FIGURE VI-3

SULFATE-1980
PERCENT OF DAYS ON WHICH STATE STANDARD WAS EXCEEDED
(24-HOUR AVERAGE $SO_4^{=} \geq 25\ \mu g/m^3$)

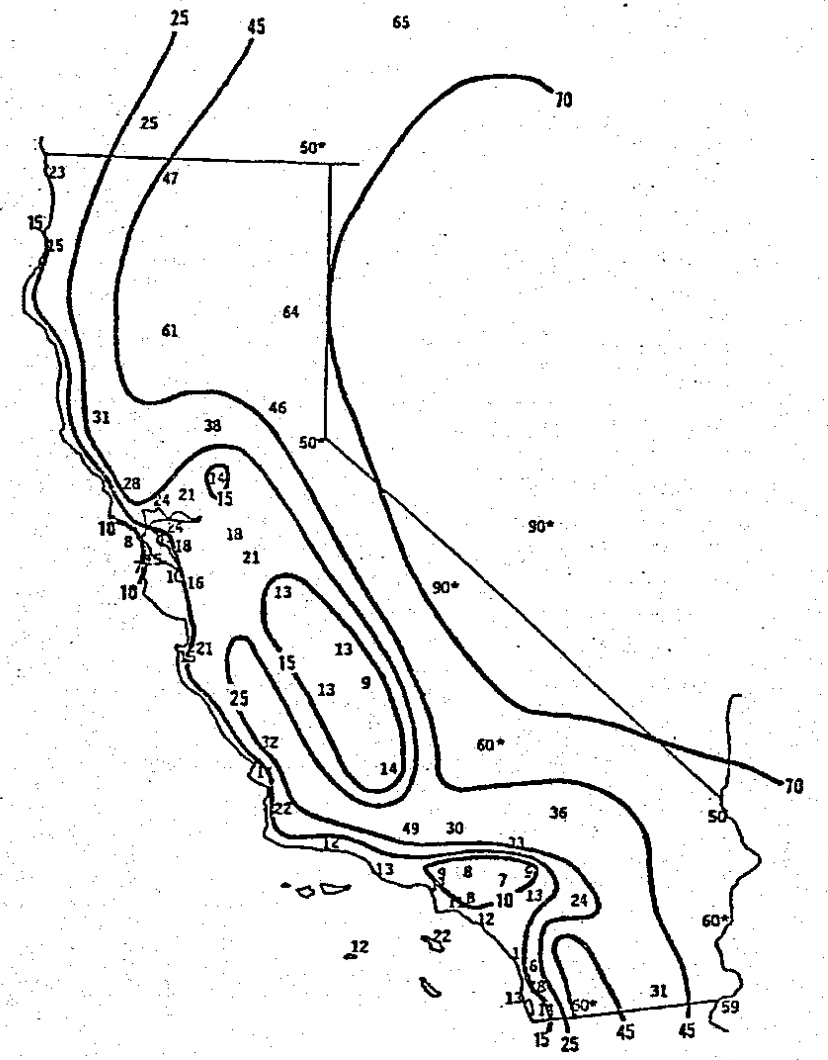


Source: Summary of Air Quality in the South Coast Air Basin of California, 1980, South Coast Air Quality Management District, May 1981.

-Less than 12 months of data.
-Not measured at this location. Sulfate is measured every sixth day.

FIGURE VI-4

MEDIAN 1 PM VISIBILITIES (IN MILES) AND
VISIBILITY ISOPLETHS FOR CALIFORNIA



Source: Air Quality and Meteorology, South Coast Air Quality Management District, September 1979.

TABLE VI-3

20-YEAR PERCENTAGE OCCURRENCE OF ADVERSE VISIBILITIES
(1958-1977)

Station (north to south)	All-month average	Rank (best to worst)	Season a/ (percentage adverse) Worst	Best	Number of qualifying observations
San Francisco	21%	3	Winter (36%)	Spring (10%)	5633
Oakland	26%	4	Fall (42%)	Spring (14%)	4793
Salinas	8%	1	Fall (17%)	Spring (5%)	5969
Santa Maria	15%	2	Fall (22%)	Winter (6%)	6343
Oxnard	32%	6	Summer (52%)	Winter (19%)	4057
Los Angeles	49%	8	Summer (63%)	Spring (37%)	5511
Long Beach	51%	9	Summer (63%)	Spring (35%)	6599
Riverside	38%	7	Summer (60%)	Winter (15%)	6851
San Diego	29%	5	Summer (37%)	Spring (21%)	6190

a/ Seasons:

Winter = December, January, February
Spring = March, April, May
Summer = June, July, August
Fall = September, October, November

Source: Visibility Trends in the Coastal Areas of California 1958-1977, Air Resources Board Technical Services Division, December 1980.

This occurs because sulfate particulates are in the size range of particles that are effective in scattering light. It has been reported that on an average for 12 separate sampling sites throughout coastal and inland areas in California, 39 percent of the visibility degradation is due to suspended sulfates.[19/]

b. Acid Precipitation

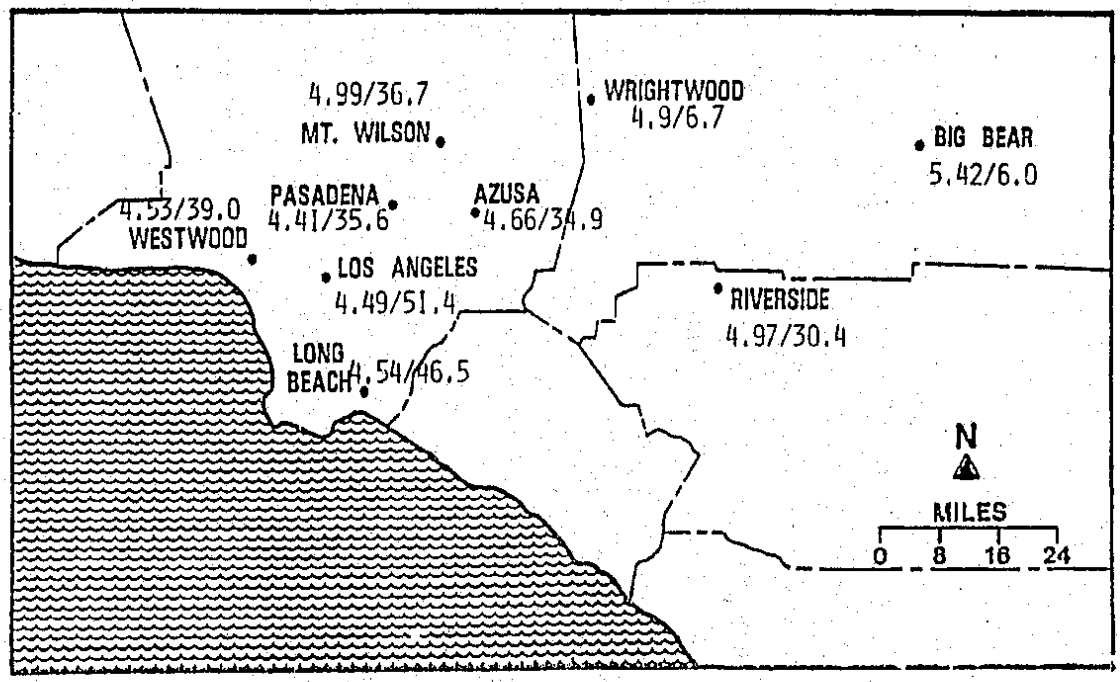
Another air pollution problem related to sulfur dioxide emissions is acid precipitation. An increasing amount of scientific research suggests that acid deposition, either as precipitation or dry deposition, may be responsible for long-term adverse environmental effects.[23/] These effects include the acidification of lakes, rivers, and groundwaters; damage to biota in aquatic ecosystems; possible changes in forests and agricultural crop productivity; demineralization of soils; deterioration of man-made materials and degradation of drinking water systems.[23/] It is not known whether these effects are occurring in California, but such effects have been documented elsewhere. Both sulfates and nitrates in the atmosphere contribute to the acidity of rain. Researchers under contract to the Air Resources Board have reported that in the South Coast Air Basin the ratio of non-sea salt sulfate to nitrate in rainfall is 0.9.[24/] Thus, sulfur dioxide emissions are nearly as important as nitrogen dioxide emissions as precursors to acidity of rainfall in Southern California.

During the fall, winter, and spring of 1978-79, precipitation samples for nine locations in the South Coast Air Basin were collected and analyzed for acidity[24/]. In Figure VI-5, the mean pH* and sulfate values measured over

* pH is the negative of the logarithm of the hydrogen ion concentration in a solution and is a measure of acidity. Solutions with pH less than 7 are acidic. As the strength of the acid increases, the pH number decreases.

FIGURE VI-5

MEAN pH/NON-SEA SALT SULFATE VALUES
(μ EQUIV/LITER) FALL 1978 - SPRING 1979



Source: A Survey of Acid Precipitation in Northern California, Final Report, California Air Resources Board, 1980.

that sampling period are displayed. As the figure shows, rainfall throughout the Basin is substantially more acidic than unpolluted rain, which has a pH of 5.65. Typically, the precipitation was 10 to 100 times more acidic than unpolluted rain. At its worst, the acidity was nearly 1,000 times that of unpolluted rain. There are currently no standards regarding precipitation acidity.

> Independent Refiner's Association of California Comment: "Acid precipitation is not a new phenomenon. However, recognition that it is an environmental problem did not occur until fairly recently in California. Furthermore, the data base on acid preciptation is rather sparse.
>
> In recognition of this, Assembly Bill 2752 was passed by the Legislature and approved by the Governor on September 27, 1982.
>
> The bill provides funding mechanisms for very comprehensive studies of Acid Deposition under the auspices of the Air Resources Board over a 5-year period but prohibits the Air Resources Board from adopting any rules or regulations to control acid deposition without further statutory authorization.

c. Air Pollution Emergency Episodes

Based on health considerations, certain ambient concentrations of various pollutants have been designated by the Air Resources Board and the EPA as emergency episode levels.[25,26/] When an air pollution episode level is reached, an air pollution control or air quality management district is required to take measures to abate activities which contribute to the high ambient concentrations of the pollutant for which the episode was declared.[25/]

Table VI-4 shows the frequency of pollutant concentrations which equaled or exceeded air pollution episode criteria levels in the South Coast Air Basin for the years 1979, 1980, and 1981. As the Table shows, there were 105 first stage oxidant episodes, 5 second stage oxidant episodes, 6 TSP episodes, and 6 sulfate/oxidant episodes in the basin during 1981.

TABLE VI-4

AIR POLLUTION EPISODES IN THE SOUTH COAST AIR BASIN

1979, 1980, 1981

Pollutant/Episode[a/]	Number of Episodes (Days)		
	1979	1980	1981
Oxidant - Stage 1 Episode[b/]	123	102	105
Oxidant - Stage 2 Episode[c/]	20	15	5
TSP Episode[d/]	2	12	6
Sulfate/Oxidant Episode[e/]	7	26	6

a/ Oxidant and sulfate/oxidant episode criteria are set by the Air Resources Board (ARB). The TSP episode criterion is an EPA criterion.

b/ ARB criterion - Oxidant concentration greater than or equal to 0.20 ppm.

c/ ARB criterion - Oxidant concentration greater than or equal to 0.35 ppm.

d/ EPA criterion for an "air pollution alert" - 375 ug/m^3. The ARB and the South Coast Air Quality Management District do not include TSP episodes in their emergency plans.

e/ ARB criterion - Sulfate concentration greater than or equal to 25 ug/m^3 in combination with an oxidant concentation greater than or equal to 0.20 ppm.

Source: Air Resources Board staff.

In addition to the episodes shown in Table VI-4, for the years 1979 through 1981 there were 6 first stage oxidant episodes in the South Central Coast Air Basin and 20 first stage oxidant episodes in the San Diego Air Basin. Also during that period, there were 3 second stage oxidant episodes in the San Diego Air Basin and 7 TSP episodes in the South Central Coast Air Basin.. There was 1 first stage oxidant episode in the San Francisco Bay Area Air Basin in the period 1979-1981.

C. COASTAL CALIFORNIA METEOROLOGY

California Coastal Waters have been defined as that area between the California coastline and a line starting at the California - Oregon border at the Pacific Ocean

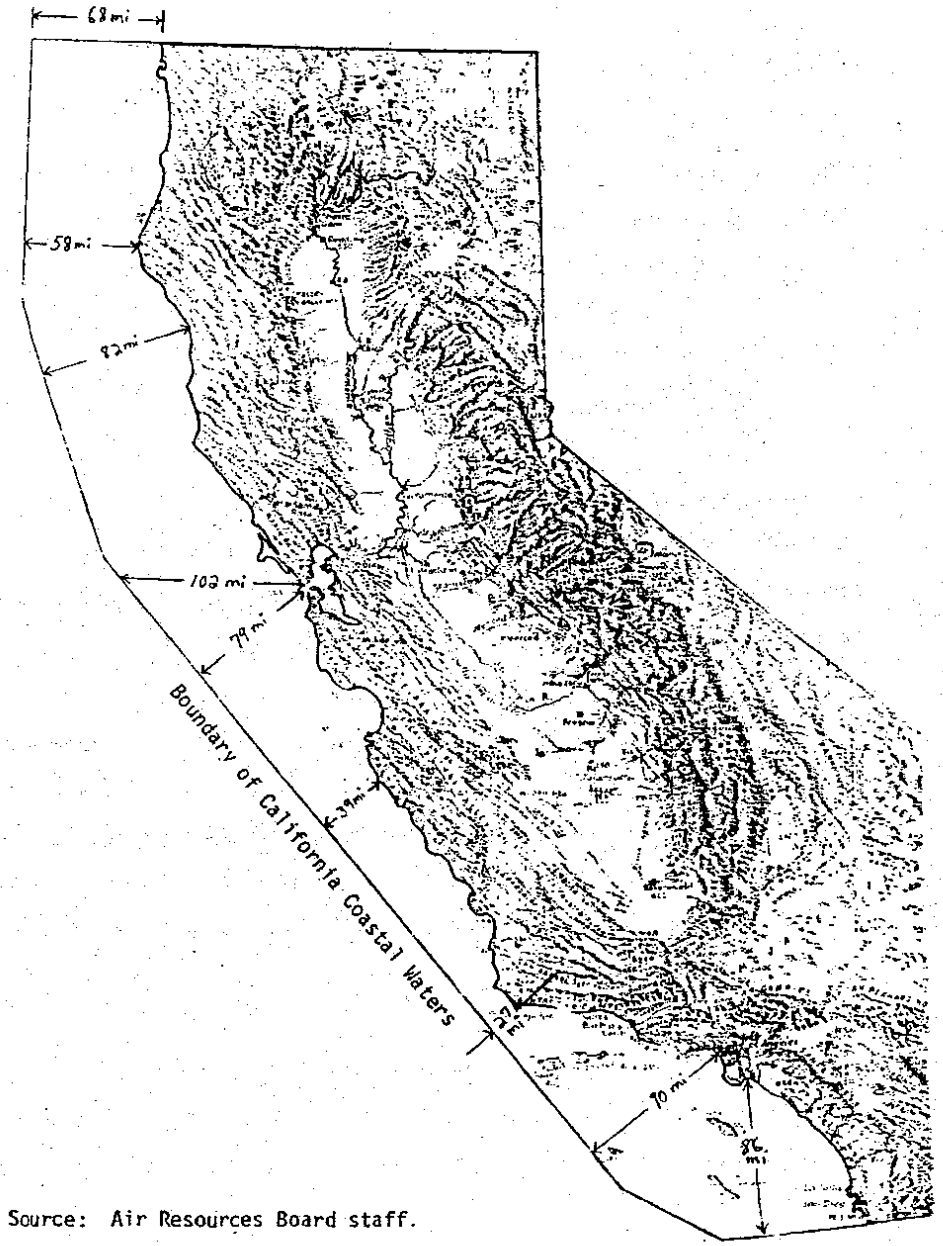
thence to 42.0° 125.5°W
thence to 41.0°N 125.5°W
thence to 40.0°N 125.5°W
thence to 39.0°N 125.0°W
thence to 38.0°N 124.5°W
thence to 37.0°N 123.5°W
thence to 36.0°N 122.5°W
thence to 35.0°N 121.5°W
thence to 34.0°N 120.5°W
thence to 33.0°N 119.5°W
thence to 32.5°N 118.5°W

and ending at the California-Mexico border at the Pacific Ocean. The California Coastal Waters are shown on Figure VI-6.

The line describing California Coastal Waters does not form a political boundary but it is useful in describing the fate of pollutants emitted off the California coast. The definition of California Coastal Waters was developed by the ARB meteorology staff and was originally presented as Appendix A to the ARB staff report, Status Report Regarding Adoption by Local Air Pollution Control Districts of Rules for the Control of Emissions from Lightering Operations, February 23, 1978. California Coastal Waters as defined above is the area offshore of California within which pollutants are likely to be transported ashore and affect air quality in California's coastal air basins, particularly during the summer. Pollutant emissions released somewhat to the west of these waters in summer are likely to be transported southward, parallel to the coast. Most coastal marine traffic passes 3 to 15 miles from

FIGURE VI-6

CALIFORNIA COASTAL WATERS



Source: Air Resources Board staff.

the coast, well within the boundaries of California Coastal Waters. Emissions released well west of these waters are likely to be transported southwestward, away from the coast.

Development of the definition of California Coastal Waters is based on over 500,000 island, shipboard, and coastal meteorological observations. These data were taken from official records of a number of agencies including the U.S. Weather Bureau, Coast Guard, Navy, Air Force, Marine Corps, Civil Aeronautics Administration and Army Air Force (see pages 11 and 12 of Appendix H-1).

WOGA Comment: WOGA does not accept the State's definition of California Coastal Waters for the reasons outlined in its legal position paper in Appendix B.

The development of the definition for California Coastal Waters is discussed in detail in Appendix H-1. The primary meteorological features of the California coastal areas that cause pollutants emitted within California Coastal Waters to be transported ashore are discussed below.

1. Pacific High Pressure Cell

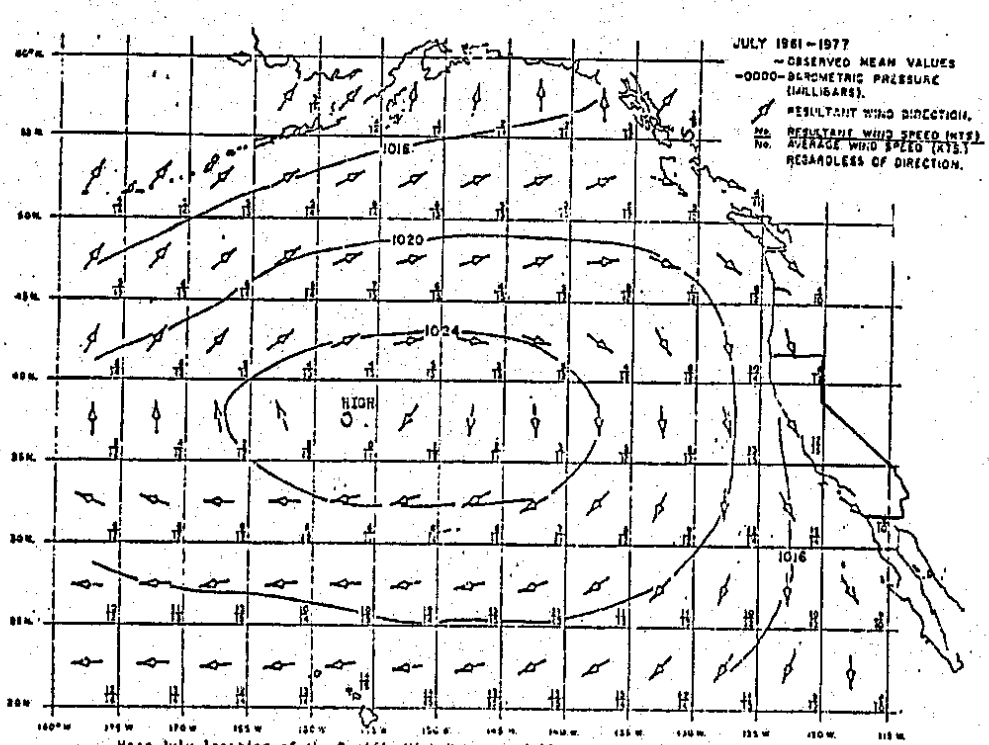
The North Pacific high pressure cell (anticyclone) is the dominant influence on the weather and climate of the eastern North Pacific Ocean and neighboring land areas in middle latitudes, particularly during the summer. It is a semi-permanent feature of the large scale atmospheric circulation pattern in the northern hemisphere and consists of an extensive deep mass of air rotating in a clockwise direction and covering much of the North Pacific Ocean throughout the year.[27/]

The basic cause of this circulation feature is the large scale thermal difference between adjacent water and land masses in middle latitudes.[27/] During summer, the water mass is much cooler than the neighboring land mass.

Through conduction and mixing, the air above the water is cooled and its density is increased thus producing a vast high pressure cell. In addition, air from the Equator enters the system aloft to provide additional support for high pressures. East of the ocean, the warm land increases the air temperature and consequently the air becomes less dense resulting in the formation of a large low pressure cell or thermal low. The positive differential of pressure from ocean and land causes a gigantic interchange of air. The warming air above the land surfaces rises and is replaced at low levels by cooler air moving onshore from the Pacific Ocean. A further interchange takes place aloft where air sinks in the Pacific high to replace the air that moved onshore. The sinking air in turn is replaced aloft by air from the tropics.

Because sinking (subsiding) air over the ocean is warmed by compression, it becomes warmer at lower levels than the air in the marine layer next to the ocean surface. The subsidence thus produces a strong persistent vertical temperature inversion which is another dominant feature of the Pacific high.[27/]

The Pacific high is strongest and most extensive in the summer when the temperature difference between the ocean and land is greatest. As the seasons progress and the sun moves southward, this ocean-land thermal discontinuity lessens and is displaced to more southerly latitudes as northern lands cool. This tends to weaken the Pacific high cell and causes it to move southward. The arrival of winter storms in middle latitudes also keeps the Pacific high somewhat suppressed thus reducing its influence in middle latitudes during winter.[27/] The average extent and location of the North Pacific anticyclone for the mid-summer and mid-winter months of July and January (seasonal extremes) are shown in Figures VI-7 and VI-8 respectively.

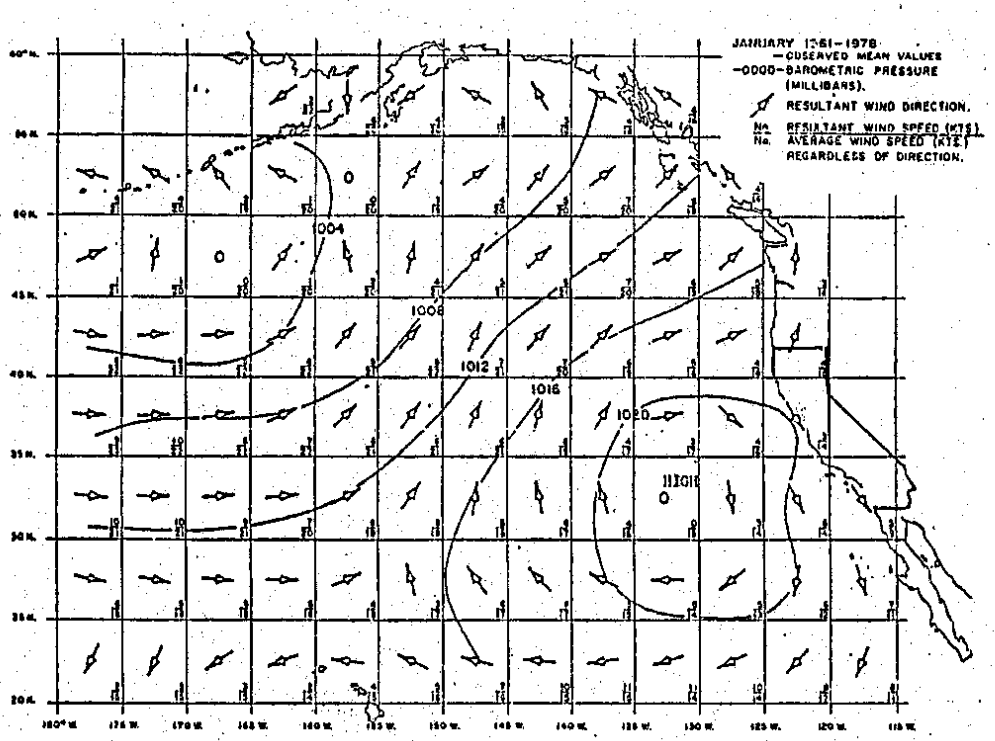


Mean July location of the Pacific High Pressure Cell. Resultant winds are shown for each 5° latitude and 5° longitude area. The wind speed numbers in the lower right hand corner of each area can be divided to obtain the steadiness ratio. Ratios between 0.7 and 0.9 (such as those found off the California coast) indicate the resultant winds are representative. Low ratios (such as those found near the center of the high cell) indicate that the individual winds varied markedly from the resultant wind direction.

FIGURE VI-7

MEAN JULY LOCATION OF THE PACIFIC HIGH PRESSURE CELL

Source: National Marine Fisheries Service, July 1977.



Mean Jan. location of the Pacific High Pressure Cell. Resultant winds are shown for each 5° latitude and 5° longitude area. The wind speed numbers in the lower right hand corner of each area can be divided to obtain the steadiness ratio. Ratios between 0.7 and 0.9 (such as those found off the California coast) indicate the resultant winds are representative. Low ratios (such as those found near the center of the high cell) indicate that the individual winds varied markedly from the resultant wind direction.

FIGURE VI-8

MEAN JANUARY LOCATION OF THE PACIFIC HIGH PRESSURE CELL

Source: National Marine Fisheries Service, January 1978.

2. Coastal California Predominant Wind Flows

The North Pacific high pressure cell produces a predominantly northwesterly flow of marine air over California Coastal Waters. This large scale circulation pattern is modified to a more westerly flow by continental influences as the air approaches the coast of California.[27/] Table VI-5 presents a summary of windflow direction frequencies measured at various locations along the California coast. The table shows that onshore windflows predominate during the spring, summer, and fall at all locations. The table also shows that the percentage frequency of offshore winds exceeds onshore winds in the winter at Vandenburg Air Force Base, Point Mugu, and Los Angeles. The greater overall frequency of onshore winds indicates a net transport of marine air, including the pollutant content of such air, into coastal air basins. This can be seen graphically in Figures VI-9 and VI-10 which show the predominant summer wind flow patterns along the coast of northern California and southern California respectively.

3. Land/Sea Breezes

The large scale climatological wind flows along the California coast as discussed above are modified by the effects of local land/sea breeze circulations. In effect, the local daytime sea breeze enhances the large-scale onshore component of the wind while the nighttime land breeze retards or on occasion reverses the flow.[28/] Table VI-6 presents seasonal resultant winds by time of day for Oakland and Point Mugu Naval Air Station (NAS) located just south of Oxnard. The table shows the influences of the land/sea breeze circulations and shows that the onshore winds are generally stronger than offshore winds, a further indication of the transport of

TABLE VI-5

Windflow Direction Frequencies in Coastal Areas of California

Station	Direction of Wind Flow	Seasonal Frequency in Percent				
		Spring[a/]	Summer[b/]	Fall[c/]	Winter[d/]	Annual
Oakland	Onshore	75%	83%	62%	47%	67%
	Offshore	20%	13%	27%	42%	25%
	Calm	5%	4%	11%	11%	8%
Vandenberg AFB	Onshore	64%	69%	48%	34%	54%
	Offshore	24%	9%	32%	53%	29%
	Calm	12%	22%	20%	13%	17%
Santa Barbara	Onshore	50%	62%	44%	32%	47%
	Offshore	26%	21%	29%	24%	25%
	Calm	24%	17%	27%	44%	28%
Point Mugu NAS	Onshore	57%	59%	41%	31%	47%
	Offshore	28%	21%	41%	54%	36%
	Calm	15%	20%	18%	15%	17%
Los Angeles	Onshore	68%	81%	60%	43%	63%
	Offshore	30%	16%	36%	53%	34%
	Calm	2%	3%	4%	4%	3%

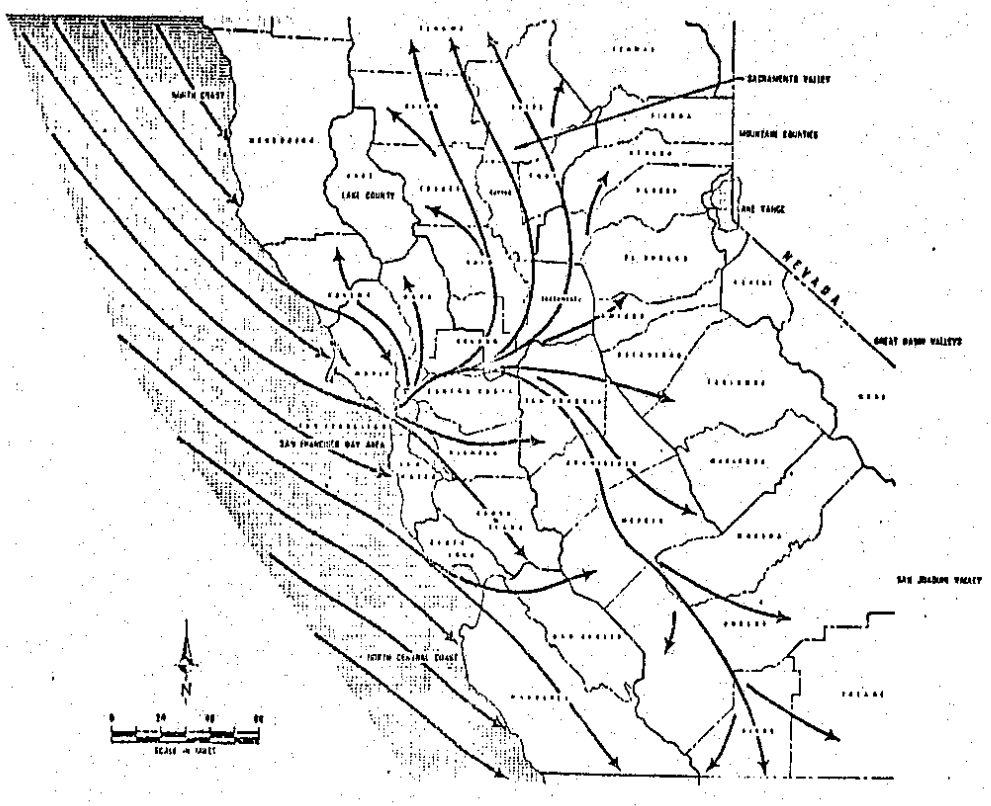
Period of Record: Oakland 1965-1978
Vandenberg AFB 1959-1977
Santa Barbara 1960-1964
Point Mugu NAS 1960-1972
Los Angeles International 1960-1978

a/ Spring: March, April, May
b/ Summer: June, July, August
c/ Fall: September, October, November
d/ Winter: December, January, February

Source: National Climatic Center

FIGURE VI-9

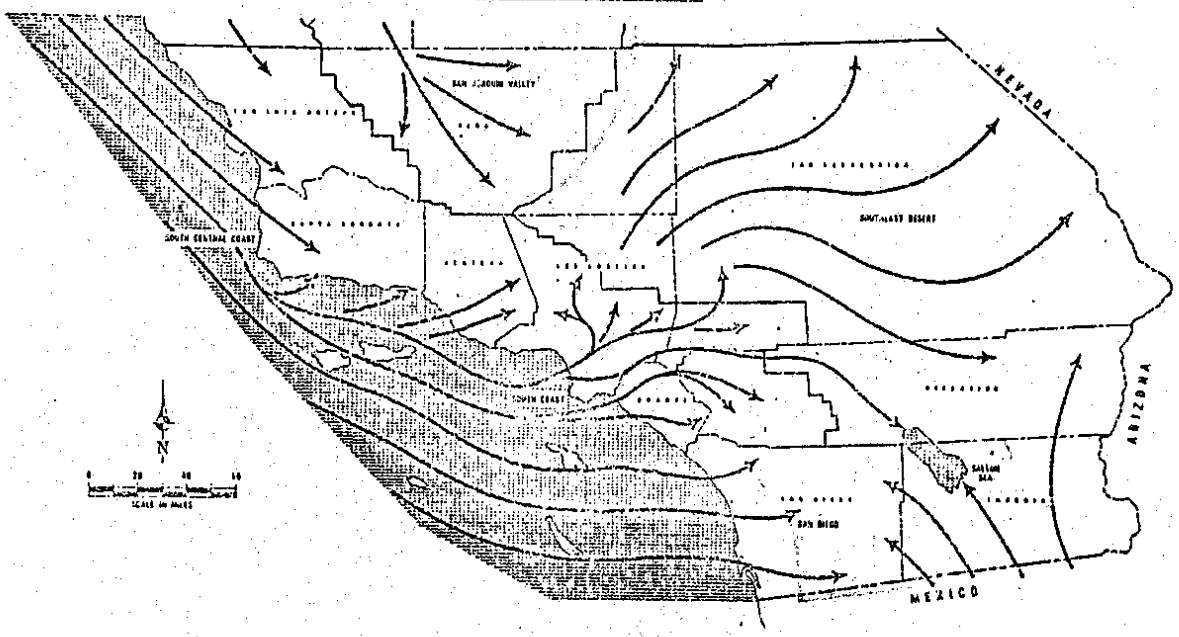
NORTHERN CALIFORNIA
PREDOMINANT WIND FLOW PATTERNS
SUMMER (JUNE, JULY, AUGUST)



Source: Air Resources Board Technical Services Division

FIGURE VI-10

SOUTHERN CALIFORNIA
PREDOMINANT WIND FLOW PATTERNS
SUMMER (JUNE, JULY, AUGUST)



Source: Air Resources Board, Technical Services Division

TABLE VI-6

Three-Hourly and Seasonal Resultant Winds
(Degrees/MPH - Onshore Winds in Parens)

Oakland

Time (PST)	Spring	Summer	Fall	Winter	Annual
0100	(270/4)	(280/6)	(300/1)	100/2	(280/2)
0400	(270/2)	(280/5)	020/1	100/2	(280/1)
0700	(230/1)	(270/4)	120/1	110/3	(220/1)
1000	(250/5)	(270/7)	(240/3)	150/2	(250/4)
1300	(270/9)	(290/11)	(280/7)	(260/4)	(280/8)
1600	(280/12)	(290/13)	(290/3)	(280/4)	(280/9)
1900	(280/9)	(290/11)	(300/6)	(320/1)	(290/7)
2200	(230/6)	(280/7)	(300/3)	080/1	(290/4)
All Hours	(270/6)	(280/8)	(280/4)	(190/1)	(280/4)

Point Mugu NAS

Time (PST)	Spring	Summer	Fall	Winter	Annual
0100	323/1	Calm	036/2	033/4	024/1
0400	007/1	029/1	032/2	036/4	030/2
0700	013/2	013/1	031/2	038/4	029/2
1000	(230/4)	(235/5)	(210/1)	052/4	(230/2)
1300	(250/8)	(252/8)	(248/5)	(230/2)	(249/6)
1600	(264/9)	(267/8)	(259/6)	(279/3)	(268/7)
1900	(279/5)	(287/4)	320/2	001/2	(297/3)
2200	(297/2)	(291/1)	002/2	022/3	340/2
All Hours	(269/3)	(264/3)	(301/1)	022/2	(288/2)

Period of Record: Oakland 1975-1979
Point Mugu 1962-1977

Source: National Climatic Center

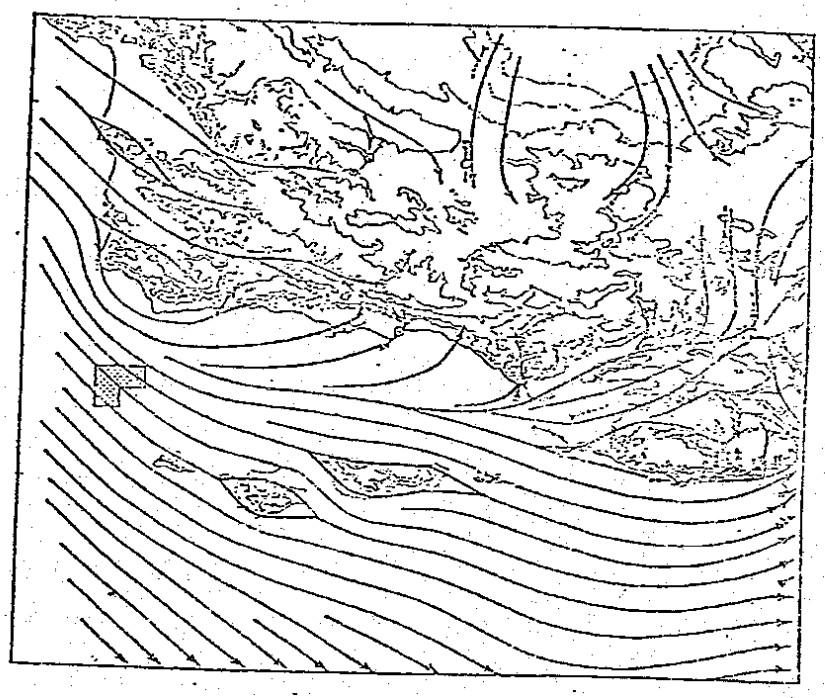
offshore emissions to receptor areas onshore. The table also shows that the fall and winter resultant winds, whether onshore or offshore, are not strong winds, having resultant magnitudes less than 7 miles per hour at the coast at all times.

4. Windflows in the Santa Barbara Channel

Analyses of airflow patterns in the Santa Barbara Channel indicate that emissions in the Channel that are not transported to the Santa Barbara or Ventura County coasts are carried into the South Coast Air Basin.[28/] Figures VI-11 through VI-14 were presented to the California Coastal Commission on October 23, 1982, as part of Chevron U.S.A.'s testimony on the determination of consistency with the Coastal Zone Management Act for proposed exploratory oil wells that Chevron proposes to drill in the Santa Barbara Channel. The figures present the airflow patterns in the Santa Barbara Channel for daytime and nighttime in both winter and summer. Figures VI-11 and VI-12 show that the daytime airflows, both in summer and winter, will transport emissions in the Channel either to Santa Barbara or Ventura County, or to the South Coast Air Basin. Figures VI-13 and VI-14 show that the nighttime windflows in the Channel tend to carry emissions into Ventura County or into the Gulf of Santa Catalina off the South Coast Air Basin. The pollutants arriving in the Gulf of Santa Catalina can be carried into the Los Angeles area as the nighttime land breeze is replaced by the daytime sea breeze.

5. Atmospheric Inversion

The air that flows around the Pacific high at upper levels sinks (subsides) and consequently warms due to air compression. This warm air above the cool coastal marine air produces a strong and persistent vertical temperature inversion that is a major influence on atmospheric stability.



JULY 1200-1800 PST

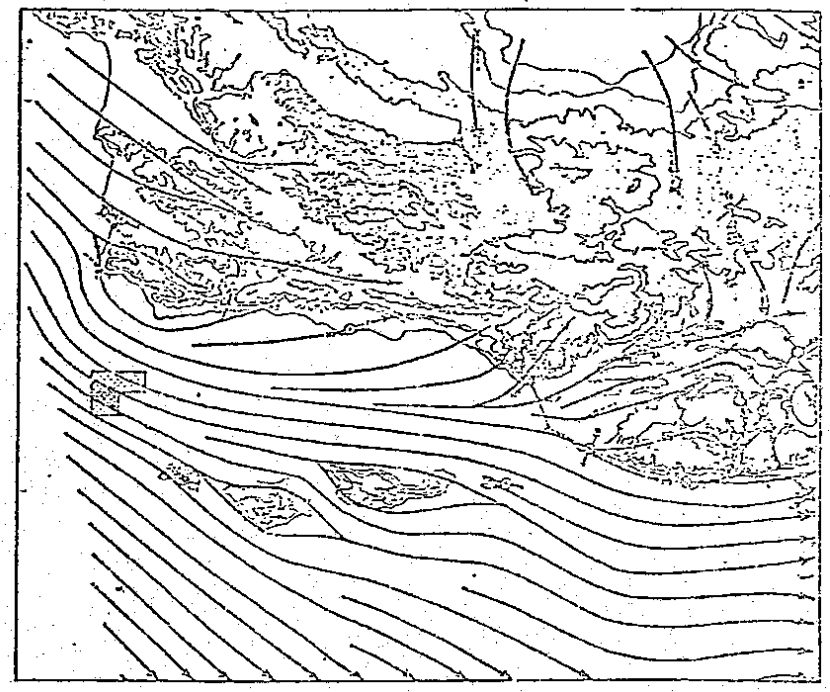
CHEVRON LEASES P-0331, P-0332, AND P-0338

FIGURE VI-11

DAYTIME AIRFLOW IN THE SANTA BARBARA CHANNEL

SUMMER

Source: Meteorological Summaries Pertinent to Atmospheric Transport and Dispersion Over Southern California, Technical Paper No. 54, G. A. DeNarrais, G. D. Holzworth, and C. R. Hosier, U.S. Department of Commerce, 1965. Taken from the testimony of Valerie Brown, Chevron, U.S.A., during the consistency hearings of the California Coastal Commission on Chevron U.S.A.'s exploratory wells on leases P-0331, P-0332, and P-0338, October 22, 1981.



JANUARY 1200–1700 PST

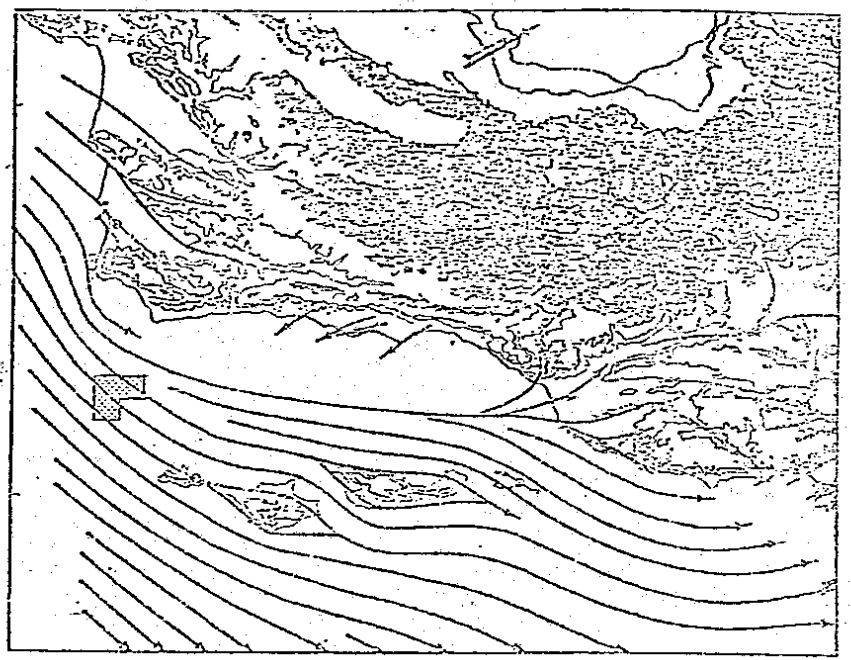
CHEVRON LEASES P-0331, P-0332, AND P-0338

FIGURE VI-12

DAYTIME AIRFLOW IN THE SANTA BARBARA CHANNEL

WINTER

Source: Meteorological Summaries Pertinent to Atmospheric Transport and Dispersion over Southern California, Technical Paper No. 54, G. A. DeMarrais, G. D. Holzworth, and C. R. Holser, U.S. Department of Commerce, 1965. Taken from the testimony of Valerie Brown, Chevron, U.S.A., during the consistency hearings of the California Coastal Commission on Chevron U.S.A.'s exploratory wells on leases P-0331, P-0332, and P-0338, October 22, 1981.



JULY 0000–0500 PST

☒ CHEVRON LEASES P-0331, P-0332, AND P-0338

FIGURE VI-13

NIGHTTIME AIRFLOW IN THE SANTA BARBARA CHANNEL

SUMMER

Source: Meteorological Summaries Pertinent to Atmospheric Transport and Dispersion Over Southern California, Technical Paper No. 54, G. A. DeMarrais, G. D. Holzworth, and C. R. Holser, U.S. Department of Commerce, 1965. Taken from the testimony of Valerie Brown, Chevron, U.S.A., during the consistency hearings of the California Coastal Commission on Chevron U.S.A.'s exploratory wells on leases P-0321, P-0332, and P-0338, October 22, 1981.

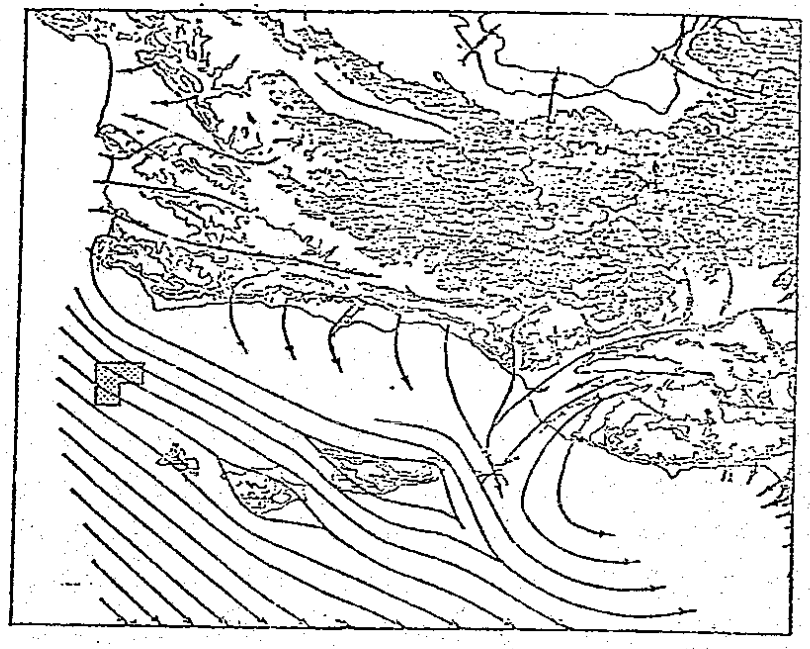


FIGURE VI-14

NIGHTTIME AIRFLOW IN THE SANTA BARBARA CHANNEL

WINTER

Source: Meteorological Summaries Pertinent to Atmospheric Transport and Dispersion Over Southern California, Technical Paper No. 54, G. A. DeHarrais, G. D. Holzworth, and C. R. Holser, U.S. Department of Commerce, 1965. Taken from the testimony of Valerie Brown, Chevron, U.S.A., during the consistency hearings of the California Coastal Commission on Chevron U.S.A.'s exploratory wells on leases P-0331, P-0332, and P-0338, October 22, 1981.

Atmospheric stability is the primary weather factor that influences the vertical dispersion of pollutants. In general, the more stable the air, the more dispersion is inhibited. An extremely stable subsidence inversion dominates the California coastal areas and effectively caps the marine layer providing a ceiling above which pollutants cannot rise. This reduces the vertical dispersion of air pollution, particularly during the summer when the inversion is strongest and most persistent.27/

Table VI-7 is a compilation of seasonal inversion frequencies and characteristics for Oakland, Vandenberg AFB, and Point Mugu NAS. The table shows that the mean height of the base of the subsidence inversion ranges between 600 and 2200 feet above sea level (asl) and is persistent throughout the year (inversions are present some 90 percent of the time). The combination of a strong persistent inversion and the onshore winds which characterize the coastal meteorology of California is conducive to the transport of offshore emissions to coastal air basins. Offshore emissions are ducted beneath or within the inversion, with little dispersion, to onshore areas.

6. Fog

The moisture content of air is another climate-related parameter which must be taken into account when considering coastal air quality. In the presence of suspended water droplets, acid precursors such as sulfur oxides can be transformed into acidic particles. Conversion of sulfur dioxide to acidic particles adversely affects ambient concentrations of sulfate and TSP, contributes to visibility degradation, and contributes to acidification of precipitation, cloud and, fog.

The climatic arrangement of warm stable air over the cool marine environment that dominates the coastal waters of California produces a relatively high incidence of fog.27/ The frequency of occurrence of fog

TABLE VI-7

Atmospheric Inversion Statistics [a/]
(Composite of 4 a.m. and 4 p.m. Soundings)

Oakland

	Spring	Summer	Fall	Winter	Annual
Mean					
Inversion Top (ft asl)	3200	2800	2900	3000	3000
Inversion Base (ft asl)	2200	1200	1700	1900	1700
Strength (Top Temp-Base Temp)	6°F	15°F	8°F	6°F	9°F
Percentage Occurrence					
Inversion	80%	98%	88%	80%	86%
Base < 3000' asl	58%	94%	71%	60%	71%
Base ≤ 1000' asl	31%	47%	44%	43%	41%

Vandenberg AFB

	Spring	Summer	Fall	Winter	Annual
Mean					
Inversion Top (ft asl)	2900	3200	2700	2600	2900
Inversion Base (ft asl)	1700	1400	1400	1600	1500
Strength (Top Temp-Base Temp)	10°F	20°F	12°F	8°F	13°F
Percentage Occurrence					
Inversion	89%	99%	93%	85%	92%
Base ≤ 3000' asl	77%	96%	85%	71%	83%
Base ≤ 1000' asl	40%	32%	50%	55%	44%

Point Mugu NAS

	Spring	Summer	Fall	Winter	Annual
Mean					
Inversion Top (ft asl)	1900	2800	2000	1400	2100
Inversion Base (ft asl)	1100	1300	1000	600	1000
Strength (Top Temp-Base Temp)	7°F	14°F	10°F	8°F	10°F
Percentage Occurrence					
Inversion	84%	99%	96%	87%	92%
Base < 3000' asl	73%	93%	86%	82%	84%
Base ≤ 1000' asl	57%	47%	66%	60%	59%

a/ Period of Record: 1975-1977

Source: Summary of California Upper Air Metecrological Data, Air Resources Board.

(visibility less than 7 miles) at Alameda NAS and Point Mugu NAS, is shown in Figure VI-15. As indicated in the figure, fog is frequent during the night and early morning hours, especially during the cold half of the year in the Bay area and during the warm half of the year in the Southern California area. In the latter case, fog is observed more than 50 percent of the time around sunrise at Point Mugu NAS. Considering all hours and seasons, fog is present on about 25 percent of the days at Alameda and on 40 percent of the days at Point Mugu.

D. TRACER STUDIES

Tracer studies are conducted by releasing known quantities of a readily detectable, inert gas into the atmosphere and sampling the atmosphere for concentrations of that gas in areas to which an air parcel could be expected to be transported. The characteristics of the transport and dispersion of air pollutants and wind patterns can thus be discerned by the tracer concentrations in the samplings.

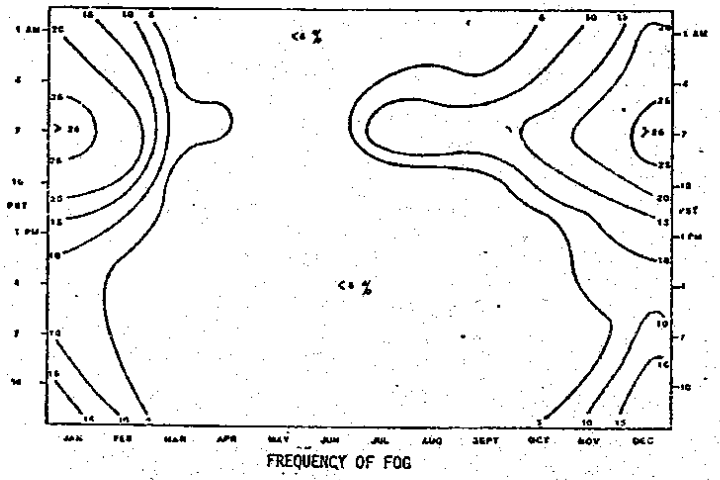
During September and October 1980, Meteorology Research, Inc. (MRI), and investigators from the California Institute of Technology (Caltech) conducted tracer studies in the Santa Barbara Channel area.[29/] A detailed summary of those tests is appended to this report as Appendix H-2. The appendix consists of the first fifteen pages of the report, Tracer Investigations of Atmospheric Transport Into, Within, and Out of the Santa Barbara Channel and the Coastal Areas of Santa Barbara and Ventura Counties, January 15, 1981.

The MRI/Caltech tracer studies were performed by conducting six releases of sulfur hexafluoride (SF_6) as the tracer gas in and around the Santa Barbara channel area. Over 2,240 hourly-averaged samples, obtained at fixed sites along the coast and inland, and about 10,000 grab samples obtained during traverses by automobiles, airplanes, and boats were collected during the studies.

FIGURE VI-15

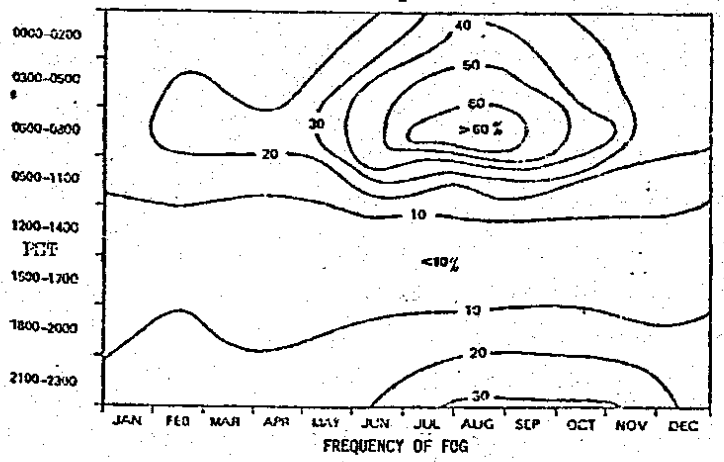
PERCENTAGE OF OBSERVATIONS REPORTING FOG
(Visibility Less Than 7 Miles)

Alameda NAS



Source: National Climatic Center

Point Mugu NAS



Source: Climatic Handbook for Point Mugu and San Nicolas Island, Par
Surface Data, Pacific Missile Range Report by Robert de Violi
March 1974.

The general aspects of the transport and dispersion were remarkably consistent from test to test. During each test, a major portion of the tracer cloud was transported efficiently onshore by the afternoon sea breeze. The transport of pollutants released from the Point Conception region was influenced by an eddy centered around Gaviota. This eddy transported the tracer material in a counter-clockwise motion into the middle of the channel, and then back to the coastal zone east of El Capitan. Over the water, the tracer was transported long distances with very little dispersion in the vertical direction. In one case, for example, the tracer was transported downwind over 60 kilometers (40 miles), but spread only 150 meters (500 feet) vertically. Such results clearly indicate that pollutant emissions from sources located in California Coastal Waters result in downwind concentrations of those pollutants onshore. In addition, these tracer releases indicate that the air over the ocean is substantially more stable than over land.

A second general feature observed is that the diurnal reversals of wind direction associated with a land-sea breeze circulation system can cause offshore pollutants to persist in the coastal area for long periods of time. For example, in one test the tracer was released over a five-hour period, and the tracer material was detected at onshore sampling stations located along a coastal distance exceeding 50 miles. The tracer was detected in the coastal region for over 19 consecutive hours. Persistence, as indicated by these results, appears to be a characteristic of offshore plumes dispersed under the conditions of diurnal reversals in wind direction. Such conditions occur frequently along the entire California coast.

These tests show that, during meteorological conditions that existed during the tracer releases, pollutants emitted virtually anywhere in the Santa Barbara Channel will be transported onshore. The tracer tests also indicate

that, during those meteorological conditions, very little dispersion occurs over water in the vertical direction and, as a consequence, pollutant concentrations downwind will be elevated. The "flow reversals" which commonly occur between offshore and onshore winds indicate that pollutants released in the Channel can persist for long periods in the coastal area. At this time, it has not been determined how far inland the pollutants emitted into the Channel can be transported. However, a study by Drivas and Shair[30/] has confirmed that atmospheric transport occurs from the Oxnard Plain (Coast of Ventura) into the San Fernando Valley of the South Coast Air Basin.

In 1977, a tracer study was conducted in and around the Santa Monica Bay to determine the fate of emissions from coastal sources in the characteristic diurnal circulation system in the South Coast Air Basin.[31/] SF_6 was released from a stack at Southern California Edison Company's El Segundo Generating Station beginning at midnight on July 22, 1977, and ending at 5:00 a.m. that day. The release of a total of 90 kilograms of SF_6 was made during the nighttime land breeze. Monitoring stations along the coast began to detect the tracer gas being transported back to shore as early as 8:00 a.m. on July 22. Mass balance calculations further showed that the daytime sea breeze had transported all of the tracer material back across the coastline by 4:00 p.m. on that same day. The study shows the occurrence of net positive transport of "fresh" marine air into the air basin despite the diurnal circulation system, as well as showing the recycling of pollutants from the land mass to sea, and back to land during the sea breeze-land breeze regime.

Another study conducted in 1977 involved the use of dual tracers. This study was designed to determine the onshore impact region of emissions from vessels operating along shipping lanes off the South Coast Air Basin and in

the Santa Barbara Channel. The tracer releases were made from the U.S. Naval Postgraduate School Research Vessel "Acania" as it moved along the northwest-bound shipping lane between Long Beach and Santa Barbara. The path of the "Acania" as releases were made is shown in Figure VI-16. A sampling network was established along a section of the coast between Long Beach and Ventura. Twenty-nine sites were chosen to locate hourly-average samplers. The locations of those sites are shown in Figure VI-17.

The study started on July 26, 1977, with dual tracer gas releases at 0530 PDT near Long Beach and was terminated at 1730 PDT in the Santa Barbara Channel. Sulfur hexafluoride (SF_6) was released at the rate of 80 lbs/hr during the entire test as the research vessel proceeded northwest from Long Beach to the Santa Barbara Channel 8 to 20 miles offshore. Bromotrifluoromethane ($CBrF_3$) was released at 50 lbs/hr between 0530-0830 PDT at the start of the test and again between 1230-1730 PDT on the last segment of the route. These two segments are shown as cross-hatched areas on Figure VI-16.

Both tracer gases were detected at sampling stations along the entire length of the sampling network. The bulk of the tracer gases began to be detected about 0900 PDT following the onset of the sea breeze. The measured concentrations were used in preliminary calculations to provide estimates that significant amounts of both tracer gases released offshore returned across the coast between the sampling network and the top of the mixed layer.

The results of this tracer test support the results of other tracer studies and the analyses of historical climatological data that show the transport of offshore emissions to onshore areas most of the time, and particularly during the summer.

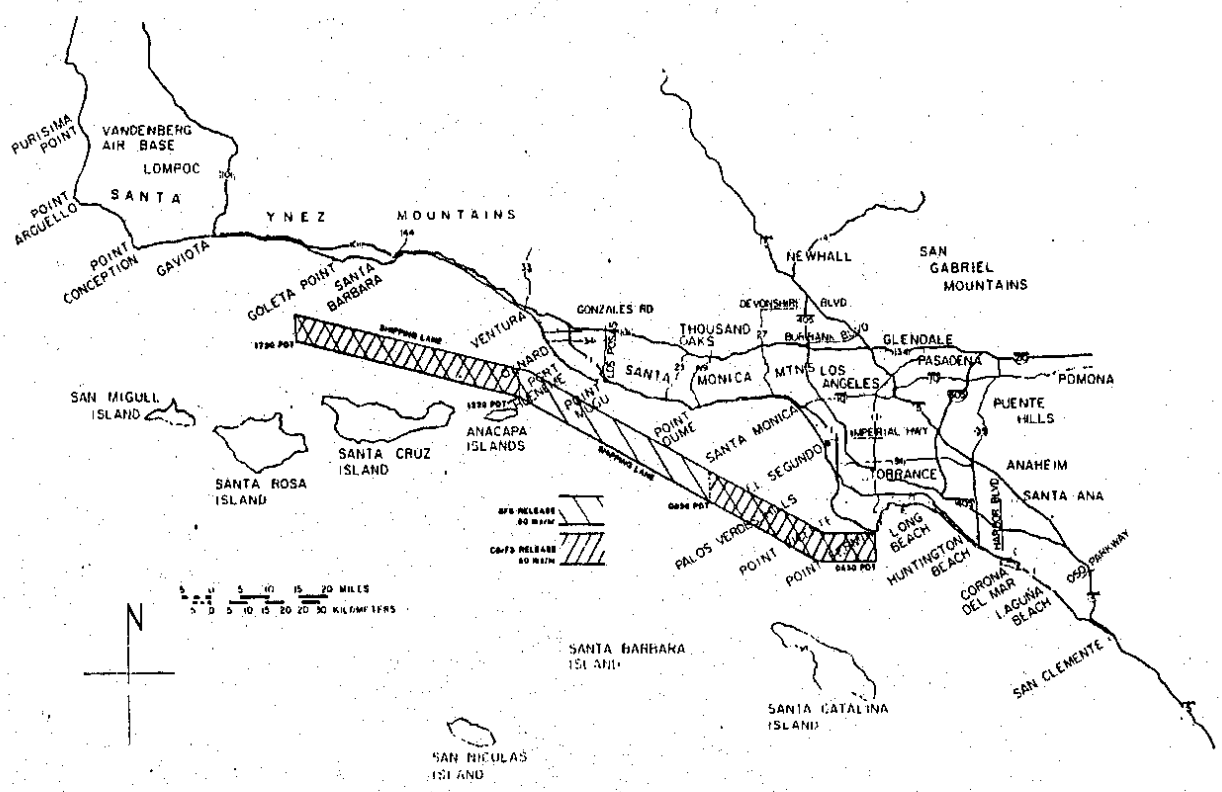


FIGURE VI-16

TRACER RELEASE DIAGRAM FOR
TRACER STUDIES OF OFFSHORE EMISSIONS

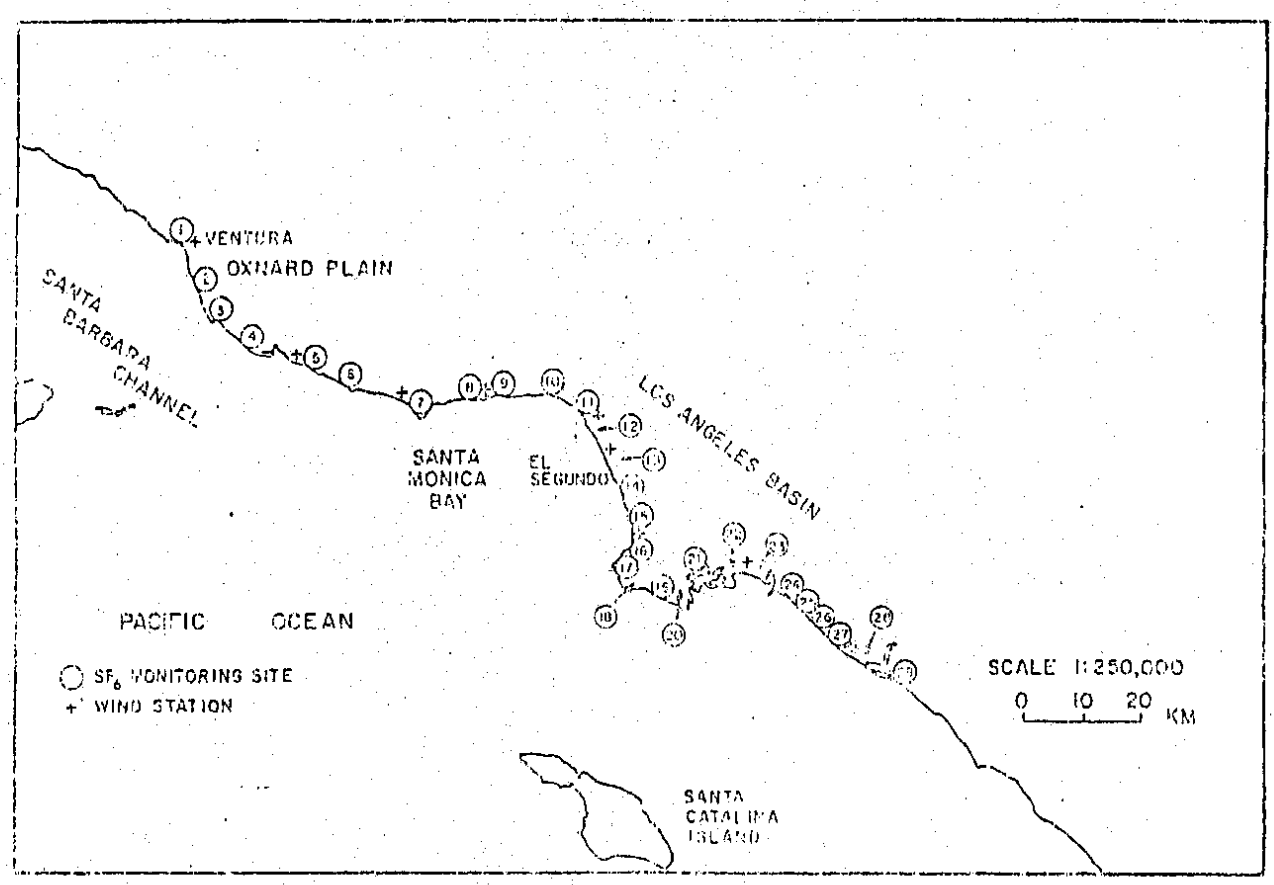


FIGURE VI-17

AIR MONITORING SITES AND
WIND STATIONS FOR TRACER STUDIES
OF OFFSHORE EMISSIONS

E. MODELING

Computer models designed to simulate, through mathematical equations, the transport, dispersion, and, sometimes, the chemical transformation of pollutants in the atmosphere can be used to estimate shoreside concentrations of pollutants released offshore. However, due to inadequate modeling formulation or lack of input data, models can predict concentrations of pollutants appreciably different from measured values. In this report, the demonstration of onshore transport of offshore emissions is based on tracer studies and meteorological analyses.

A series of screening modeling exercises were performed by the ARB staff and by Environmental Research & Technology, Inc. (ERT) to identify the upper limit of air quality impacts of sulfur dioxide emissions on receptors in the South Coast Air Basin. The ERT modeling was performed under a contract from the Western Oil and Gas Association. Three separate scenarios were modeled by the ARB staff: (1) emissions from vessels within the Ports of Los Angeles and Long Beach; (2) emissions from a single ship moving northwest along the coast; and (3) emissions from a tanker unloading at El Segundo. ERT also modeled scenarios (2) and (3). Both the ARB staff and ERT used Gaussian air quality models and considered shoreline fumigation conditions to determine the maximum one-hour onshore concentrations of sulfur dioxide. For offshore sources, it was assumed that a plume traveled from a source (ship's stack) to the coastline under stable conditions. At the coastline, erosion of the inversion layer often begins due to the thermal heating of the ground surface resulting in fumigation. The dispersion coefficients used by the ARB staff and ERT, although different, are based on studies of atmospheric dispersion over water. The ARB staff relied on the study results presented in a report

prepared by the California State Lands Commission (1982)[32/] while ERT relied on results reported by Schacher, et al. (1982).[33/] Details of the ARB staff and ERT's modeling analyses are presented in Appendices F-1 and B-4 respectively. The following briefly describes the results of the ARB and ERT modeling analyses.

The one-hour air quality analysis of emissions from ships in the Los Angeles-Long Beach harbor area, as modeled by the ARB staff, assumed an emission rate of 8.4 tons per day of sulfur dioxide for that "area source." Under a fumigation scenario, the maximum one-hour ground level sulfur dioxide concentration, above ambient levels, is estimated at 99 micrograms per cubic meter (ug/m^3). This value occurred about 1.6 miles inland from the shoreline and can be compared with the California one-hour standard of 1,310 ug/m^3. On November 18, 1983, the Board approved a new 1-hour standard for ambient concentrations of sulfur dioxide of 0.25 ppm or about 655 ug/m^3. That standard will be in effect following its approval by the Office of Administrative Law.

The emissions impact of a ship moving along the coast was modeled by both the ARB staff and ERT by assuming a continuous moving source at varying distances from the coast. The maximum onshore one-hour ground level concentration of sulfur dioxide (above ambient levels), as modeled by the ARB staff, is 7 ug/m^3. The ERT analysis shows a maximum estimated ground level sulfur dioxide concentration of 5.1 ug/m^3. The difference between the two results is attributable to differences in the turbulent parameters and model formulations used by the ARB staff and ERT.

The third scenario modeled was for a tanker unloading at Chevron's offshore terminal at El Segundo. The ARB staff analysis shows that, under fumigation conditions, the emissions from such a tanker resulted in a maximum one-hour ground level sulfur dioxide concentration, above ambient levels, of 394 ug/m^3. That value is predicted to occur 1.4 miles inland from the coastline. The ERT analysis resulted in a maximum one-hour ground level sulfur dioxide concentration, above ambient levels, of 127 ug/m^3. Again, the difference between the ARB and ERT results is attributable to differences in turbulent parameters and model formulations used by the ARB staff and ERT. The modeling performed by the ARB staff provides an upper limit estimate for the worst-case situation. ERT argues that the ARB staff applied a modeling formulation and over-water turbulent parameters that are not based on the best available theoretical and experimental information. However, the ARB staff believes that based on the offshore meteorology for worst-case conditions and the limited data bases available to characterize over-water dispersion of air pollutants, both modeling approaches are adequate for a screening analysis. The estimates presented in this report probably represent the range of the upper limits of sulfur dioxide concentrations that may occur for the conditions simulated.

The concentrations discussed above are in addition to concentrations resulting from emissions from other sources. The one-hour air quality standard for sulfur dioxide is 1,310 ug/m^3. On November 18, 1983, the Board approved a new 1-hour standard for ambient concentrations of sulfur dioxide of 0.25 ppm or about 655 ug/m^3. That standard will be in effect following its approval by the Office of Administrative Law.

F. AIR QUALITY IMPACTS OF MARINE VESSEL EMISSIONS

There are health-related air quality standards for sulfur dioxide, sulfates, total suspended particulate (TSP), and ozone in California. There is also a standard for visibility. The standards for sulfates, TSP, and ozone are frequently violated in coastal air basins. The question is, "What is the contribution of marine vessel emissions to the degradation of air quality compared to emissions from other sources?" To answer that question, we have shown that the meteorology of California's coastal areas results in emissions from marine vessels generally being transported to inland coastal areas. In addition, the results of tracer studies show that pollutants emitted by marine vessels are transported to shore during releases in meteorological regimes typical of California's coastline. To compare the relative impact of various sources, it is common to consider an air basin as a large box in which all of the pollutants become mixed. The relative impact of a particular source is determined by calculating its fractional or percentage contribution to total emissions. Table VI-8 compares sulfur dioxide emissions from all sources with sulfur dioxide emissions from marine vessels in each of the coastal air basins from San Francisco to San Diego. Table VI-8 shows that sulfur dioxide emissions from marine vessels range from 8.2 percent of total sulfur dioxide emissions in the San Diego Air Basin to 21.8 percent in the North Central Coast Air Basin, averaging 12.0 percent in the coastal air basins shown in the table. Therefore, using the box model, marine vessels would account for the same percentage of ambient sulfur dioxide and sulfate concentrations.

Because sulfur dioxide becomes, in large part, suspended particulate matter, marine vessels would contribute to ambient TSP. Assuming that one-third of visibility reduction is caused by sulfate particles, about 4 percent of visibility reduction in coastal areas is attributable to emissions from ships.

Table VI-8

COMPARISON OF AVERAGE DAILY EMISSIONS OF
SULFUR DIOXIDE FROM MARINE VESSELS WITH EMISSIONS OF
SULFUR DIOXIDE FROM ALL SOURCES IN CALIFORNIA COASTAL AIR BASINS
1979

Air Basin	Emissions of Sulfur Dioxide from All Sources	Emissions of Sulfur Dioxide From Marine Vessels	
	Tons per day	Tons per day[a]	Percent of Total
San Francisco Bay Area	195.9	26.1	13.3
North Central Coast	33.0	7.2	21.8
South Central Coast	88.8	15.7	17.7
South Coast	262.4	22.6	8.6
San Diego	55.9	4.6	8.2
All of the Above	636.0	76.2	12.0

a/ Sea lane emissions were apportioned to coastal air basins by traffic activity and by dividing the coast south of the Sonoma-Mendocino County line into 6 zones by extending to the west the air basin boundaries at the coast and ratioing the north-south distances between those extended boundaries to the total north-south distance between the Sonoma-Mendocino County line and the boundary of California and Mexico.

Source: Air Resources Board staff.

The precursors to ozone are atmospheric hydrocarbons and oxides of nitrogen. Control strategies for ozone have emphasized hydrocarbon reductions. Table VI-9 compares hydrocarbon emissions from all sources with hydrocarbon emissions from marine vessels in each of the coastal air basins from San Francisco to San Diego. Table VI-9 shows that hydrocarbon emissions from marine vessels range from 0.5 percent of the total hydrocarbon emissions from all sources in the South Coast Air Basin to 3.4 percent in the South Central Coast Air Basin, with an average in those coastal air basins of 1.0 percent. Therefore, using the box model, hydrocarbon emissions from marine vessels would account on the average for from 0.5 to 3.4 percent of ambient ozone concentrations in those coastal air basins. Hydrocarbon emissions from tankers and barges on a given day can be several times the average daily rate because of the event-related nature of emissions. Therefore, the contribution to ozone concentrations would also be several times the average daily contribution on those days. Hydrocarbons are, in substantial part, converted to suspended particulate matter in the atmosphere. Therefore, tanker and barge hydrocarbon emissions make a contribution to ambient TSP concentrations and to visibility reduction.

The foregoing contributions of sulfur dioxide and hydrocarbon emissions to air quality degradation may seem small to some readers, but it must be borne in mind that nearly all sources of emissions are very small compared to total emissions. Therefore, it is necessary to consider controls on all sources of emissions, using cost effectiveness as the criterion for regulation.

Table VI-9

COMPARISON OF AVERAGE DAILY HYDROCARBON EMISSIONS
FROM MARINE VESSELS WITH HYDROCARBON EMISSIONS
FROM ALL SOURCES IN CALIFORNIA COASTAL AIR BASINS
1979

Air Basin	Emissions of Hydrocarbons[a] From All Sources	Emissions of Hydrocarbons From Marine Vessels	
	Tons per day	Tons per day[b]	Percent of Total
San Francisco Bay Area	767	11.4	1.5
North Central Coast	106	1.7	1.6
South Central Coast	182	6.2	3.4
South Coast	1520	7.8	0.5
San Diego	277	2.3	0.8
All of the Above	2852	29.4	1.0

a/ Reactive organic gases.

b/ These are annual average hydrocarbon emissions from marine vessels. Since most emissions from marine vessels are event-related, emissions from vessels on a given day can be several times the above figures shown. In developing this table, sea lane housekeeping and breathing emissions were apportioned to coastal air basins by tanker activity and by dividing the coast south of the Sonoma-Mendocino County line into 6 zones. The 6 zones were developed by extending to the west the air basin boundaries at the coast and ratioing the north-south distances between those extended boundaries to the total north-south distance between the Sonoma-Mendocino County line and the boundary of California and Mexico.

Source: Air Resources Board staff.

Santa Barbara County APCD Comment: I have some real concerns that the loading of this particular crude or, the burning of high sulfur fuels or the blowing of boilers at these near shore marine terminals may impact more than just the reactive hydrocarbon inventory. In the coastal counties many of these marine terminals are near the residential areas and often times are less than 5000 ft. offshore. In many of our cases, it is less than a thousand feet offshore and numerous complaints are received as a result of loading vapors which contain hydrocarbons, hydrogen sulfide or mercaptans, or as a visible emission resulting from blowing of boilers or a cold start on a diesel engine.

Response: The ARB concurs with this concern.

Air Quality Impacts from NOx Emissions of Two Potential Marine Vessel Control Strategies in the South Coast Air Basin

Final Report

September 2000

Prepared by the California Air Resources Board and the South Coast Air Quality Management District in Consultation with the Deep Sea Vessel/Shipping Channel Technical Working Group

California Environmental Protection Agency

Air Resources Board

South Coast
Air Quality Management District

ACKNOWLEDGMENTS

This report was developed by Air Resources Board and South Coast Air Quality Management District staffs in consultation with members of the Deep Sea Vessel/Shipping Channel Working Group. We would like to acknowledge the following members of the working group for their active participation in the comparative technical analysis on which this report is based and for their assistance in preparing the final report:

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Thomas Jelenic, Port of Long Beach
Scott Johnson, Ventura County Air Pollution Control District
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LIST OF ACRONYMS & ABBREVIATIONS

To aid the reader, the following list of acronyms and/or abbreviations used throughout the document is provided.

Acronym	Explanation
ARB	Air Resources Board
BATS	Automated Sequential Samplers
BNL	Brookhaven National Laboratory
CATS	Passive Samplers
g/kWh	Grams per kilowatt-hour
NOx	Oxides of Nitrogen
PMCP	Perfluoromethylcyclopentane
PMCH	Perfluoromethylcyclohexane
PDCH	Perfluoro-1,2-dimethylcyclohexane
PTCH	Perfluorotrimethylcyclohexane
PDCB	Perfluorodimethylcyclobutane
POLA	Port of Los Angeles
POLB	Port of Long Beach
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
SCOS97-NARSTO	1997 Southern California Ozone Study-North American Research Strategy for Tropospheric Ozone
SIP	State Implementation Plan
TWG	Deep Sea Vessel/Shipping Channel Technical Working Group
UAM	Urban Airshed Model
U.S. EPA	United States Environmental Protection Agency

EXECUTIVE SUMMARY

The Ports of Long Beach and Los Angeles, with ready access to Southern California's extensive rail and road network, are two of the busiest ports in the nation. In 1998, the Ports had a combined container volume of 7.3 billion TEUs (1 TEU is equivalent to one 20-foot cargo container unit) and moved goods worth 160 billion dollars. The Ports are integral players in the Southern California economy and are planning for continued growth over the next 20 years as the global marketplace expands and results in increased international trade and commerce.

The coastal waters off Southern California are also key operational waters for the United States Department of the Navy including the Pt. Mugu Sea Test Range. Aside from providing critical training, research and development, test and evaluation, and other operational assets, the Department of the Navy represents a $9.5 billion direct economic contribution to the San Diego economy, and a nearly $2 billion direct economic contribution to the Ventura County economy. These installations exist in their present location largely due to their proximity to these operationally-realistic and coastal region conditions.

The emissions from ocean-going ships contribute to the air quality problems that have long plagued Southern California. The strategy to improve air quality is identified in the 1994 Ozone State Implementation Plan (SIP). To address the emissions from marine vessels, it includes control measure M-13 "National and International Emission Standards for Marine Vessels" that is assigned to the federal government and, among other things, commits to achieving approximately a 30% reduction in the cruising emissions from ocean-going ships in 2010. M-13 did not mandate a particular control strategy to realize these reductions but did identify two possible operational controls-voluntary speed reduction and relocation of the existing commercial shipping lane to an area further offshore.

The Deep Sea Vessel/Shipping Channel Technical Working Group (TWG) conducted a comparative technical analysis of the air quality impacts between two potential operational control strategies for submittal to the United States Environmental Protection Agency (U.S. EPA). Based on the technical analysis, which relied both on data collected from a tracer dispersion study of ship emissions and model simulations of the emissions of NOx from offshore shipping and the resultant net onshore mass flux, the TWG reached the following conclusions:

- Reducing the speed at which ships travel reduces the flux of NOx emissions that reach onshore. The magnitude of the reductions is dependent upon the degree of speed reduction and the distance traveled at the reduced speed with the reductions proportional to the distance traveled and the reduced speed.

- The impact of moving the shipping lane further offshore on the onshore flux of NOx emissions is more sensitive to meteorological conditions. On some days there is an

emission reduction benefit and on other days there is a disbenefit, depending on the specific weather and wind conditions.

I

INTRODUCTION AND BACKGROUND

This report summarizes a comparative technical analysis of the air quality impacts for two potential marine vessel control strategies originally included in a proposed 1994 Federal Implementation Plan and subsequently incorporated in the South Coast 1994 Ozone State Implementation Plan (SIP). This analysis was conducted by the Deep Sea Vessel/Shipping Channel Technical Working Group (TWG) for submittal to the United States Environmental Protection Agency (U.S. EPA). The analysis was undertaken with the expectation that the U.S. EPA would incorporate the results of the analysis in a public process to select an appropriate strategy for implementing the SIP measure for marine vessels (M-13) that was identified in the 1994 Ozone SIP as a federal assignment. The TWG only assessed the air quality impacts between the two control strategies and did not address other issues that will need to be considered when formal rule-making action takes place such as cost-effectiveness, technical and commercial feasibility, and national security impacts. In this report, we provide a short review on the need for emission reductions from marine vessels, the formation of the technical working group and the technical approach used for the comparative analysis as well as the results from that analysis. Finally, we provide our findings and recommendations for U.S. EPA to consider in its deliberation on control strategies for marine vessels.

A. BACKGROUND

The need for a comparative technical analysis between the two potential control strategies became apparent during discussions on feasible ship emission reduction strategies for the South Coast Air Basin (SCAB) and ultimately led to the formation of the TWG. To provide perspective, below we briefly describe the need for emission reductions from marine vessels, the federal consultative process that generated a study to collect additional technical data to improve the understanding of the impacts of ship emissions, and the formation and goals of the TWG.

Need for Reductions from Marine Vessels

The SCAB violates the federal ozone standard more frequently, and by a greater margin, than any other area in California. The strategy to attain the federal standard for ozone in the SCAB is laid out in the 1994 Ozone SIP, and relies on control measures that affect the entire range of emission categories, including marine vessels. To address the emissions from marine vessels, the 1994 Ozone SIP includes control measure M-13 "National and International Emission Standards for Marine Vessels" that is assigned to the federal government and commits to achieving a 9 ton per day NOx emission reduction in 2010 in the SCAB based on a projected 1990 baseline inventory.

M-13 identifies several possible options for achieving the needed emission reductions from marine sources, including national and international emission standards, and operational controls such as moving commercial ocean ships further offshore and reducing ship speeds. [1]

Public Consultative Process

While U.S. EPA did not agree that states have the authority to make a SIP assignment to U.S. EPA, the Agency agreed that the Federal government should voluntarily help achieve emission reductions from sources beyond the regulatory authority of the State, particularly in view of the unique reduction needs of the South Coast, the only ozone nonattainment area classified as "extreme" under the 1990 federal Clean Air Act Amendments. As such, when the U.S. EPA approved the 1994 Ozone SIP in 1997, the U.S. EPA committed itself to a "Public Consultative Process" (PCP) to work with the various stakeholders to investigate adoption and implementation of the measures to achieve the emission reductions assigned to the federal government (62 FR 1150-1187). Under the PCP, U.S. EPA held a series of stakeholder meetings between November 1996 and May 1998 to discuss strategies to reduce pollution associated with the marine vessel sector. The federal PCP was formally concluded in 1999; however, U.S. EPA committed to continue a focused cooperative effort to agree upon the best approach for achieving reductions from marine vessels. As part of a settlement agreement with several environmental groups, U.S. EPA has agreed to propose rulemaking for the federal assignments by the end of calendar year 2000 and complete final rulemaking in calendar year 2001 (64 FR39923-27).

During the course of the PCP meetings to address marine emissions, three workgroups were formed including the Deep Sea Vessel/Shipping Channel workgroup. This workgroup focused on control strategies for deep sea vessels. After numerous discussions on various control options for deep sea vessels, the Deep Sea Vessel/Shipping Channel workgroup focused on two plausible strategies for reducing emissions using voluntary operational controls – reduce ship speeds and/or relocation of the existing shipping lane. These strategies were originally identified in the 1994 Ozone SIP as potential candidates for consideration. Both of these operational controls are potentially controversial and the workgroup desired sound technical data on which to base any decision.

Tracer Dispersion Study

To gather the necessary technical data, the Deep Sea Vessel/Shipping Channel workgroup prepared a Memorandum of Agreement (MOA) to implement a study to examine trajectories of marine vessel air emissions. The study, entitled "Tracer

[1] The South Coast Air Quality Management District updated the Air Quality Management Plan of the South Coast Air District in 1997. In this update, the M-13 control strategy was unchanged but the emission reduction commitment was increased to 15 tons per day, reflecting an increased estimate of the total NOx inventory for marine vessels that was made in 1996. On April 10, 2000, U.S. EPA finalized approval of the ozone portion of the revised plan. (65FR18903)

Dispersion Study of Shipping Emissions During SCOS-NARSTO" (tracer study), was designed to gather sound scientific data on which to base decisions on the transport of emissions from vessels using the existing and an alternative shipping channel. Signatories to the MOA included the U.S. EPA, the ARB, the South Coast Air Quality Management District (SCAQMD), the United States Navy (U.S. Navy), the Ports of Long Beach and Los Angeles, the Steamship Association of Southern California and the Pacific Merchant Shipping Association, each contributing monies to fund the $400,000 tracer study. Two contractors were selected to conduct the technical aspects of the study, Brookhaven National Laboratory and Tracer Environmental Sciences and Technologies, Inc. (Tracer ES&T) The primary objective of the study was to obtain direct evidence regarding the relative impacts of pollutants emitted from offshore sources on onshore air quality, specifically from the current and an alternative proposed shipping lane. The study was also designed to provide valuable data to validate existing meteorological models and to link the study with the 1997 Southern California Ozone Study-North American Research Strategy for Tropospheric Ozone (SCOS97), a large-scale intensive research effort intended to generate updated data regarding ozone episodes in southern California. Parallel to this effort, U.S. EPA contracted with Arcadis, Geraghty, & Miller to assess the benefits of future emission standards and alternative strategies, including a strategy to reduce ship speed.

Deep Sea Vessel/Shipping Channel Technical Working Group

As part of a commitment to participate in the federal consultative process the Air Resources Board (ARB) convened a technical working group in the summer of 1998. The goal of this working group, the "Deep Sea Vessel/Shipping Channel Technical Working Group" (TWG) was to ensure the analysis of the scientific data results in a clear understanding of the air quality benefits of two alternatives under consideration - relocation of the existing shipping lanes and voluntary speed reduction. Members include those parties that had participated in the Deep Sea Vessel/Shipping channel workgroup that was established under the federal consultative process. Participation was open to the public, but invitations were initially extended to representatives of the SCAQMD, ARB, U.S. EPA, the Ports of Los Angeles and Long Beach, the U.S. Navy, Pacific Merchant and Shipping Association, Steamship Association of Southern California, the City of Los Angeles, the U.S. Coast Guard, and the Coalition for Clean Air.

The primary goal of the TWG was to perform a technical analysis of the two alternatives, relocation of the existing shipping lanes and voluntary speed reduction, that incorporates the results of the tracer study. The TWG met approximately bi-monthly over a 2-year period beginning in June 1998. At the meetings the members discussed and reached consensus on the approach for the comparative technical analysis of the air quality impacts of the two alternative operational controls under consideration, the data inputs (emissions inventory) for the technical analysis, analysis of the tracer study results, and the recommendations for U.S. EPA. As mentioned earlier, the TWG only considered the air quality impacts and did not address the other

factors that may need to be considered when a decision is made regarding the most appropriate operational control for marine vessels.

References

Federal Register, Volume 62, pages 1150-1187, Approval and Promulgation of Implementation Plans; California-Ozone, January 8, 1997.

Federal Register, Volume 64, pages 39923-39927, Approval and Promulgation of State Implementation Plans; California-South Coast, July 23, 1999.

Federal Register, Volume 65, pages 18903 – 18906, Approval and Promulgation of State Implementation Plans; California – South Coast, April 10, 2000.

II

POTENTIAL EMISSION CONTROL STRATEGIES

The two key operational emission control strategies that emerged during the discussions on emission controls for deep sea marine vessels were a voluntary speed reduction option and relocation of the existing shipping lanes further offshore. Both of these options involve modifications to the way ships are normally operated as a means to generate emission reductions. In this chapter, we briefly describe the two operational control strategies and provide a brief synopsis of the technical approach used to compare the air quality impacts between the two options.

A. VOLUNTARY SPEED REDUCTION

Reducing the speed of a vessel results in emission reductions from the propulsion engines. At reduced speeds a ship requires less power from the engine to move the ship, which tends to decrease emissions. While reducing the speed also results in more time to travel a given distance, the overall emissions are lower because the emissions associated with the increased travel time is less significant (linear with ship speed) than the decreased power requirements (power is approximately proportional to the ship speed, cubed) (ARCADIS, May 6, 1999).

Ships traveling along the existing shipping lanes travel at various speeds, the speed being dependent on several variables. Data collected on ships arriving at and leaving the Ports of Long Beach and Los Angeles for a 60 day period in 1998 (September 22-November 22, 1998) reveals a range of speeds. In Table II-1 we summarize the average cruising speed for 3 ship types. These speeds were recorded at the 25-mile line off shore and for all practicable purposes one can assume that at that point, the ships are operating at cruising speed. (McKenna, January 6, 1999) Once the ships enter the precautionary zone, an area approximately 5 miles from the breakwater, the ships are required to travel at a speed limit of 12 knots.[2] About one mile from the breakwater the ships slow to about 5 knots to take on a pilot and then maneuver into the harbor at low speeds.

[2] The emissions impacts from this voluntary speed reduction requirement that was instituted on March 1, 1994 was not accounted for in the projected 1990 baseline inventory used in the 1994 Ozone SIP, but was reflected in the inventory used in the most recent 1997 SIP revision for the South Coast. In the 1997 SIP, we estimate there was approximately a 6 percent reduction (about 1.7 tons per day) in the projected baseline emissions that can be attributable to the precautionary zone speed limit. See Appendix B for methodology.

Table II-1
Average Speed by Ship Type

Ship Type	Cargo Carriers	Passenger	Liquid Bulk Carriers
Average MAREX Speed, knots	17.9	13.60	13.68
Average Design Speed, knots	19.58	20.40	15.31
Count	1341	111	231
Average Count per day	22	2	4

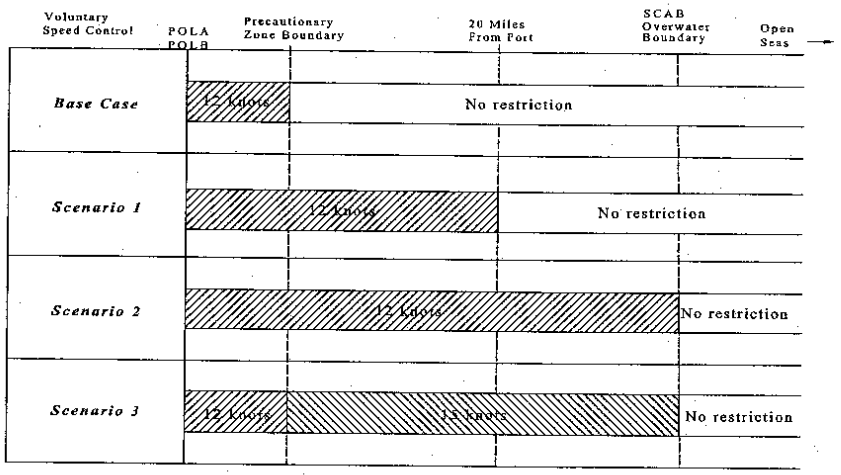
Notes: Cargo Carriers include container ships, auto carriers, breakbulk etc. The average MAREX speed was calculated from data collected by the Marine Exchange on ships traveling the existing shipping lane from September 22 to November 22, 1998. The average design speed was obtained from Lloyd's Maritime Information Services, Inc.

As indicated above, reducing the speeds below these observed values will result in emission reductions. The TWG explored various speed reduction scenarios considering the reduction in speeds, the distance over which that lower speed would be in effect, and the reasonableness of implementing the speed reductions. Three test cases were identified to be evaluated in the comparative analysis of the air quality impacts between the two operational controls. While the TWG acknowledged that the U.S. EPA will need to take into consideration many factors when designing a control strategy, these test cases were believed to bracket the range of potential speed controls that would ultimately be considered by the U.S. EPA.

The first test case or scenario was extension of the precautionary zone speed limit of 12 knots to 20 miles offshore. In this scenario, ships that had been traveling in excess of 12 knots in the waters past the precautionary zone would reduce their speeds to 12 knots. The second speed reduction scenario is to extend the 12 knot precautionary speed limit to the overwater boundary[3] of the SCAB waters; and last, the third test case was to require a speed limit of 15 knots between the overwater boundary of the SCAB and the precautionary zone. In each of the scenarios, it is assumed that ships traveling in excess of the speed limit would reduce their speeds to that limit, and that ships traveling at speeds lower than the speed limit would not increase their speed to the limit specified. It is also assumed that no other changes in the ship operational procedures would occur, i.e. ships would not speed up beyond the restricted area to make up time and ship speeds both while traveling in the breakwater and maneuvering within the ports would remain the same. For illustrative purposes, in Figure II-1, we have provided a simplistic representation of the base case and 3 speed reduction scenarios.

[3] The overwater boundary of the SCAB is delineated by straight line extensions perpendicular to the coast of the overland SCAB boundaries (the Ventura-Los Angeles County line to the north and the San Diego-Orange County line to the south) out to the point where the straight line extensions intersect with the California Coastal water boundary – approximately 100 miles offshore in the SCAB.

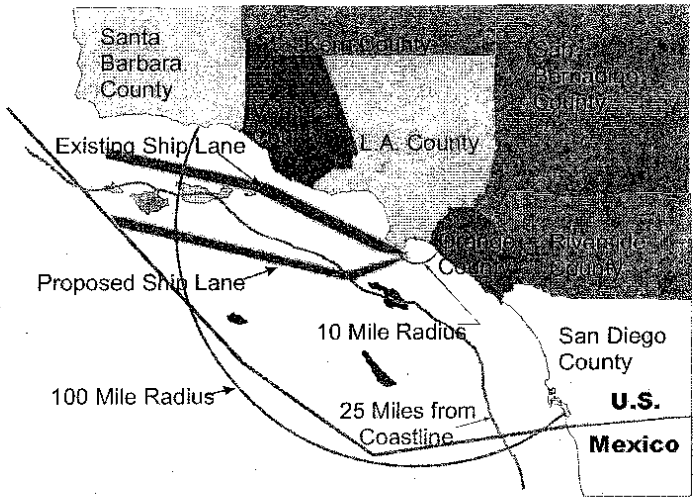
Figure II-1
Voluntary Speed Reduction Test Scenarios



B. RELOCATION OF THE SHIPPING LANE

The second operational control evaluated by the TWG is relocation of the shipping lane to a region further offshore than the existing lane. The approved 1994 Ozone SIP included a commitment to evaluate movement of the shipping lane based on the premise that movement of the shipping channel further off the coast would reduce the impact of marine vessel emissions on air quality in the SCAB. The existing shipping lane traverses the coast at approximately 10-15 miles offshore. While the 1994 SIP did not specify a location for a relocated shipping lane, it was originally proposed in the 1994 Federal Implementation Plan (FIP) for the South Coast Air Basin to move the shipping lane to further than 25 miles offshore (approximately 6-10 miles off the Channel Islands). Several of the TWG members indicated that the proposed "FIP" shipping lane may not be realistic due to a sharp "dog-leg" in the path directly outside the port and the fact that it passes through the U.S. Navy test range at Pt. Mugu. However, because the tracer study released the tracer gases in both the existing shipping channel and the proposed FIP shipping lane, the TWG agreed, for the purposes of the comparative analysis, to limit the comparison of the emissions impacts to these two tracks. The proposed and existing shipping lanes are depicted in Figure II-2 below.

Figure II-2
Existing and Proposed Shipping Lanes for the Ports of Los Angeles and Long Beach



During several of the discussions on relocation of the existing shipping lane, the TWG identified parameters that may change if ships are required to travel in a shipping lane further offshore. These included speeding up to make up the additional time needed to travel a longer route and ships potentially having to idle outside the missile test range prior to passage. However, the TWG agreed that trying to predict any changes in operational patterns was outside the scope of this comparative analysis and that for the analysis being prepared by the TWG, it will be assumed that ship operational characteristics will be the same for ships traveling in the proposed and existing shipping lanes, with the only difference being the travel route.

C. TECHNICAL ANALYSIS APPROACH

To evaluate the air quality impacts from the two potential control strategies, the TWG: 1) used the results of the tracer tests to provide a measurement based assessment of the onshore impacts between the proposed and existing shipping lanes; and 2) used an air quality dispersion model with a windfield that has been validated with the tracer data to perform a comparative analysis between the two control options by quantifying the differences in ship NOx emissions that reach onshore in the SCAB. September 4th and 5th, 1997 were selected for the model simulations since they were both a tracer release event and an episode day for the SCOS97. Photochemical modeling was outside the scope of this effort due to the lack of a complete emission inventory and time considerations, but will be used when the SCAQMD develops a comprehensive AQMP

in the 2001 timeframe. At that time, photochemical and other air quality models will be used to assess both the ozone and fine particulate matter impacts from all sources, including ships.

To accomplish these assessments, several tasks were undertaken to provide the necessary technical data. These tasks are briefly described below and in more detail in the following chapters.

Baseline Emission Inventory: Baseline day-specific ship NO_x emission inventories were developed based on the best available data. Information on individual ship type, speed, travel route, and composite data for ship types for stack height and temperature were used to generate the baseline inventory for August 3-7, 1997. The period August 3-7, 1997 was selected as representative because high ozone levels typical of a high ozone summer day were measured during that time period, and the ships operating in the SCAB waters during that period were a representative cross section of ships that call at southern California ports during the summer ozone season.

Emission Inventory for Proposed Control Options: NO_x emission inventories were created for both the proposed and existing (baseline) shipping lanes as well as for the three speed control scenarios selected for evaluation using the same methodology as for creating the baseline emission inventory.

Gridded Emission Inventory: The baseline and proposed control option inventories were gridded using an ARB shipping emissions model. This model grids ships as moving point sources and provides estimates of hourly resolved emissions for each 2km grid cell.

Tracer Data QA/QC and Normalization: Because of unforeseen problems, adequate funds were not available to have the contractor complete the analysis of the tracer data as originally planned. In lieu of generating additional funding to complete the analysis, and to ensure that the original objectives of the tracer study were met, ARB staff completed the analysis in consultation with the TWG. This work entailed reviewing the data generated by Brookhaven to verify its completeness and clarity and to review the data for outliers or otherwise questionable or non-representative data. The data were also normalized to account for differences in tracer release amounts, chemical characteristics, and ship speeds.

Assessment of Tracer Results for the Existing and Proposed Shipping Lanes: To compare the atmospheric impacts for releases in the existing and proposed shipping lanes, the normalized average station tracer peak concentrations for the morning and afternoon tracer releases were calculated for Ventura County, SCAQMD, and San Diego County on each of the tracer release days. The ratios of impacts (average normalized station peaks) from the proposed shipping lane to those in the existing lane for the SCAQMD were then developed for each of the comparable releases. Ratios less than 1.0 imply greater dispersion from the proposed lane and ratios greater than

1.0 imply less dispersion from the proposed lane. Ratios near 1.0 imply similar dispersion for the two lanes.

Windfield Preparation and Validation: A windfield validation analysis was included as part of the windfield development process and peer review was provided by a group of meteorologists and air quality modelers with expertise in the southern California region. To validate the windfield, the observed concentrations from the tracer experiment on September 4, 1997 were compared with the simulation results using the CALMET meteorological model and the CALGRID air quality model. Two approaches were used: 1) comparison of the relative distribution of mass from tracers released offshore through vertical planes defined from line segments representing each of Ventura, Los Angeles, Orange, and San Diego Counties; and 2) comparison of observed and simulated tracer distribution ratios (X/Q)

Model Simulations: An Eulerian air quality modeling system (CALMET meteorological model and CALGRID air quality model) was applied to two episode periods (August 4-7, 1997 and September 4-5, 1997) to assess the relative impacts of shipping emissions from the shipping lane and speed scenarios representing each control strategy. For each of the control scenarios the emissions of NOx from offshore shipping were simulated and the net onshore mass flux into the SCAB was calculated. Comparisons of the mass flux among the scenarios were made for each day of the two episodes simulated.

Comparative Analysis: The results from the modeling analysis and tracer analysis were compared to arrive at qualitative conclusions regarding the air quality impacts of the two shipping control strategies. Results of the tracer analysis allowed for comparison between the proposed and existing shipping lanes by providing an estimate of the dispersion onshore of NOx emissions released from transiting ships. The modeling simulations provided for a comparison between the two proposed control strategies (movement of the shipping lanes and voluntary speed reductions) as well as a comparison between the 3 speed reduction scenarios that were identified.

Throughout the working group process, a number of issues were raised on which the TWG reached consensus that the issues were beyond the scope of the comparative analysis being conducted by the TWG. These issues are described in Appendix A "Scope of Analysis."

References

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